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SAHIWAL CATTLE: AN EVALUATION OF THEIR POTENTIAL CONTRIBUTION TO MILK AND BEEF PRODUCTION IN AFRICA

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SAHIWAL CATTLE: AN EVALUATION OF THEIR POTENTIAL CONTRIBUTION TO MILK AND BEEF PRODUCTION IN AFRICA

By

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ABSTRACT

Productivity data were analyzed from five cattle herds, including Sahiwals, varying percentages of Sahiwal/Ayrshire crossbreds, Small East African Zebus and Borans, across a range of production systems and management levels in Kenya. Examination of environmental and genetic parameters indicates that the formation of composite breeds is a promising approach to producing cattle adapted to the major ecological zones and production systems of Africa. Such composites would include an optimum percentage of the highest performing *Bos indicus* breeds, such as the Sahiwal, to achieve adaptability to the production environment, combined with *Bos taurus* breeds which have a high response capability for milk and beef production.

KEY WORDS

Sahiwal, Ayrshire, Africa, Kenya, environmental effects, breed effects, heterosis, composite breeds, milk, beef, productivity index.

PREFACE

The data analyzed and discussed in this report result from a unique opportunity to evaluate the Sahiwal cattle breed and its crosses with *Bos taurus* and indigenous *Bos indicus* breeds across a wide range of management levels and production systems in tropical Africa.

Gratitude is due to the owners and managers of the five herds whose data were analyzed, both for the high quality of the data recording they have carried out and for the enthusiastic assistance they provided. Special thanks are also due to M de Souza for the meticulous extraction and preparation of these data for necessary analyses, to S B Westley for editorial assistance in preparing the report and to G Maloba for final typing. N Nissen took an active part in the initial planning of the project and B Cole-Baker was involved in the early stages of data preparation. ILCA colleagues in Addis Ababa and Nairobi provided stimulating discussions and other inputs relating to this study and ILCA administrative personnel provided substantial support throughout the course of the work.

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1. INTRODUCTION

Throughout the world, food requirements favour the use of cattle that can produce both milk and beef for human consumption. Africa has a great need to increase milk and meat production from cattle, and perhaps a great potential if specific constraints can be alleviated. Climate and associated factors in most parts of Africa, including nutrition, disease and parasite environment, favour the use of germ-plasm with varying percentages of *Bos indicus* cattle because of their higher level of adaptability to environmental stresses.

However, the response capability for milk and meat production characters is generally low in most breeds of *Bos indicus* cattle as straightbreds. Different breeds of *Bos taurus* cattle have greater genetic potential for milk and meat production characters, but in many African situations it is not economically feasible to provide the environment necessary for them to realize this potential. Thus, the most logical approach to increasing production appears to be some modification of the environment, as technically and economically practical, combined with the use of organized crossbreeding programmes or the formation of composite breeds based on *Bos indicus* and *Bos taurus* parental stock.

Though the possibilities for environmental modification are limited, it should be feasible to improve both the quantity and quality of forage production, to provide shade and to achieve a higher level of control over specific diseases and parasites. A breeding programme must then be in harmony with the environment

as modified and with the prevailing economics of production in each situation.

Kenya is the only country in Africa with major resources of *Bos indicus* Sahiwal cattle and serves as an important source of stock and semen for the continent. Within Kenya, the main utility of the breed is seen in crossbreeding for dual-purpose production in middle- to lower-potential areas. The contribution of the Sahiwal breed to adaptability is well documented in several ecological zones of Africa where Sahiwals have been crossed with exotic *Bos taurus* breeds that have a high response capability for milk and beef production but lack adaptability to local conditions. The Sahiwal breed also is considered unequalled in transmitted effects for milk production among *Bos indicus* breeds.

Meyn (1974) notes that the introduction of Sahiwals from India and Pakistan during the colonial era ended attempts to select an improved indigenous dairy breed of *Bos indicus* cattle for smallholders in the highlands of Kenya. It soon became evident that Sahiwals, when crossed with exotic *Bos taurus* breeds, produced more milk than the indigenous *Bos indicus* cattle (Mahadevan et al, 1962). Later evidence showed that in the fertile highlands *Bos taurus* cattle of European origin or their crosses with Sahiwals produced still higher milk yields than purebred Sahiwals (Mason, 1965). Meyn and Wilkins (1973) and Kimenyi and Russell (1975) further suggested that crosses of European *Bos taurus* breeds with Sahiwals outyielded their purebred herdmates of either breed in both the semi-arid highlands and the hotter and more humid coastal belt. It was hypothesized that the drier zones could not meet the requirements of crosses with the high-performing *Bos taurus* breeds, and that improved *Bos indicus* breeds, with lower nutritive requirements and greater adaptability to drought conditions, would be more suited to the more arid environments, even though their production response capability was relatively low. For these arid areas, the Sahiwal breed was considered a suitable dual-purpose dairy/beef breed to replace the indigenous Small East African Zebu.

In both semi-arid and coastal areas, a two-breed rotational crossbreeding

system, combining Sahiwals with a European dairy breed, was considered feasible. If the breeding female had a hump, she was mated to a humpless bull, whereas a humpless female was mated to a Sahiwal bull. According to Kamau (1977), government policy in Kenya during the colonial era encouraged the use of Sahiwals by small African farmers under relatively poor management conditions; this policy tended to prevent them from acquiring *Bos taurus* cattle of European origin. This effect, he argues, led to the nearly total rejection of the Sahiwal breed by African farmers when this restrictive policy was lifted. There are now indications, however, that small producers in lower-potential areas are recognizing that Sahiwal crosses with *Bos taurus* breeds have considerable potential for increasing both milk and beef production within the resources available.

The establishment of the National Sahiwal Stud at Naivasha in 1962 marked the beginning of a programme to produce a dual-purpose *Bos indicus* breed to be kept under extensive pasture conditions with minimal supplemental feeding. The aim was genetic improvement for milk and beef production, and stock were supplied for artificial insemination and sale for both pure breeding and crossbreeding in coastal and drier inland areas (Meyn and Wilkins, 1974).

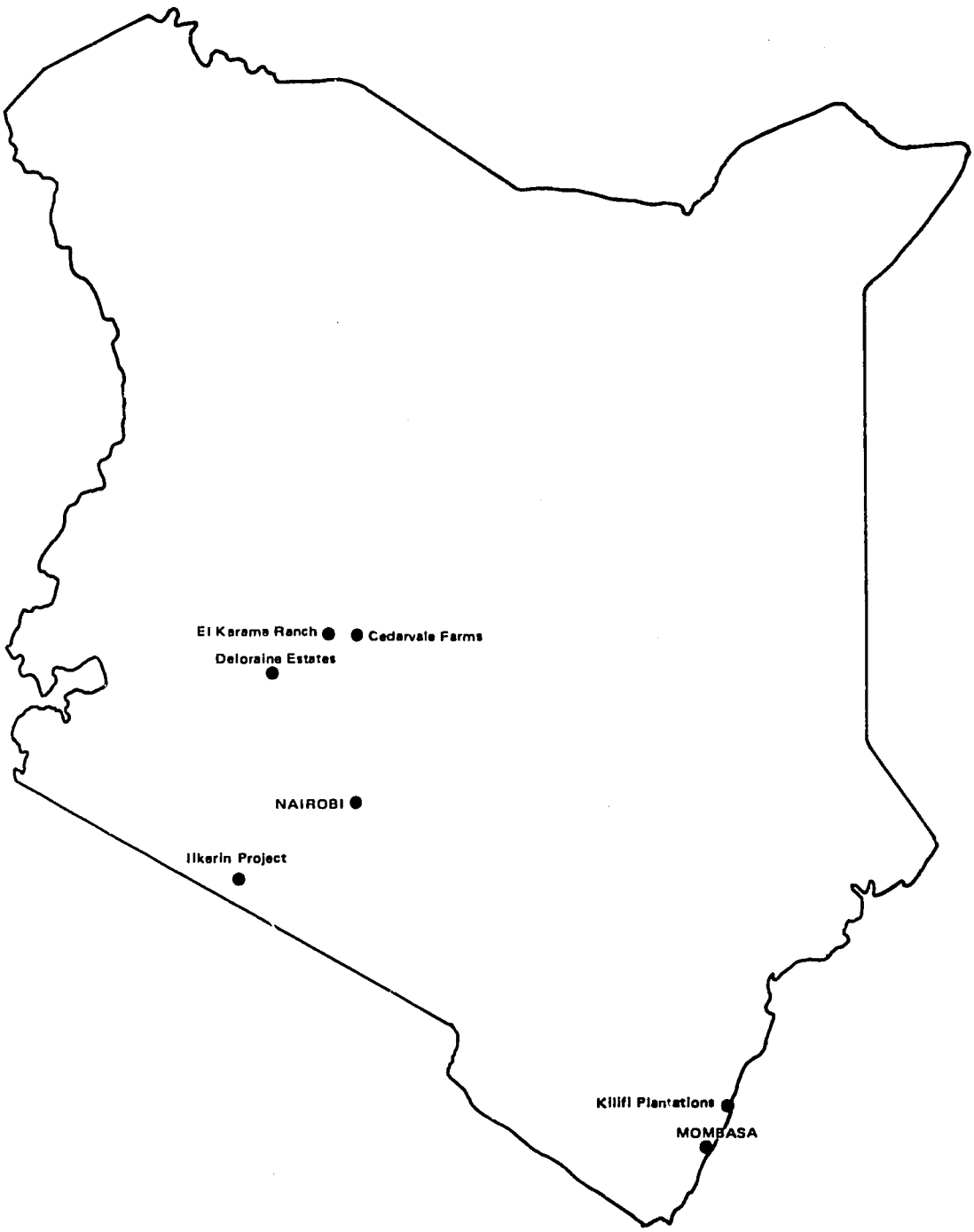
A number of private breeders have also established nucleus Sahiwal herds, generally maintained alongside crossbred commercial herds. The Sahiwal Breeders Society recognizes three categories of Sahiwal: foundation animals have at least seven-eighths Sahiwal ancestry and have passed inspection, purebred Sahiwals are minimally the progeny of registered animals above foundation stock and have passed inspection and weight-for-age evaluations and pedigree Sahiwals are minimally the progeny of registered animals above foundation stock and have passed inspection, weight-for-age, and dam's minimal lactation evaluations. This evaluation policy of the Sahiwal Breeders Society, requiring weight-for-age and milk-production information, has actively encouraged the recording of these characters in a number of private herds.

Trail (1980) has reviewed published performance criteria for indigenous, exotic and crossbred cattle in Africa south of the Sahara over a 30-year period.

Although considerable success has been reported with individual breeds and crosses, important questions remain concerning which breeds of both *Bos indicus* and *Bos taurus* cattle to use, and how to use them - whether as purebreds, or in different crossbreeding systems, or in the formation of composite breeds - given the different feed environments and production situations found throughout Africa. Moreover, the available performance data are generally not suitable for integration into any overall indices of productivity. Only about 20% of 500 bibliographic references contain information on three or more characters sufficient to allow characterization of breed types through a productivity index, or provide comparative information on two or more breed types. Only 5% of the items provide sufficient data to allow breed comparisons on the basis of a productivity index.

The objectives of the present study were to evaluate and compare the productivity under commercial management levels of Sahiwals, Sahiwal/Ayrshire crosses, indigenous Small East African Zebus and Boran, taking the range of management levels and production systems represented by the five Sahiwal-based herds for which data were available. These data, and the results reported here, are from sites in the lower-potential highlands and, in one case, on the coastal belt of Kenya. All of these sites fall within the semi-arid to subhumid zone, as classified by Trail (1980) based on cattle adaptability considerations in Africa south of the Sahara.

1. **Location of research sites in Kenya**



2. KILIFI PLANTATIONS

2.1 BACKGROUND INFORMATION

Kilifi Plantations is a private ranch of 2500 ha at the Kenya coast near Kilifi, north of Mombasa. Sisal is grown for export and milk is produced which is retailed in the surrounding area. The ranch is located at approximately 10 m above sea level on the Indian Ocean at 3.5^{o} latitude south. Annual rainfall averaged 1043 mm from 1972 through the first half of 1978, the period during which data were collected for this study, and ranged from a low of 558 mm in 1974 to a high of 1261 mm in 1972. The main rainy season was from April through June, with a shorter rainy period in September and October, but some rain fell every month throughout the study period.

Data were recorded from two breeding groups, one approximately 2/3 Sahiwal and 1/3 Ayrshire and the other 2/3 Ayrshire and 1/3 Sahiwal. These were produced from a continuous two-breed rotation crossbreeding system begun in 1939 by the initial use of purebred Sahiwal sires on Ayrshire dams. Subsequently, for the most part, females by Sahiwal sires have been mated to Ayrshire sires and females by Ayrshire sires have been mated to Sahiwal sires. Approximately equal numbers of animals were recorded in each breeding group from 1972 through the first half of 1978. Information on the characters analyzed and the number of animals recorded is given in Table 1.

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Table 1. Least-squares breeding group means and standard errors for maternal and growth characters, Kilifi Plantations

Breeding group[a]	Age at first calving		Calving interval		Lactation yield		Annual lactation yield
	N	days	N	days	N	kg	kg
2/3 Sahiwal - 1/3 Ayrshire	463	1042[b] ± 8.0	954	390[b] ± 3.6	954	2662[b] ± 39	2[illegible]03[b] ± 32
2/3 Ayrshire - 1/3 Sahiwal	482	1019[c] ± 6.5	707	398[c] ± 4.6	707	2843[c] ± 50	2616[c] ± 42

	Birth weight		Average daily gain from birth to 50 kg	Average daily gain from [illegible] to 90 kg	Average daily gain from birth to 90 kg	Calf survival	
	N	kg	g	g	g	N	%
2/3 Sahiwal 1/3 Ayrshire	874	31.4[b] ± 0.28	349[b] ± 6.5	599[b] ± 6.9	472[b] ± 4.3	1063	86[b] ± 2.2
2/3 Ayrshire - 1/3 Sahiwal	806	28.5[c] ± 0.21	408[c] ± 4.9	617[c] ± 5.2	517[c] ± 3.5	921	87[b] ± 1.7

[a] Both populations had stabilized with approximately 2/3 of the genes from the breed of the sire and 1/3 from the breed of the maternal grand-sire following several generations of a two-breed (Ayrshire and Sahiwal) rotation crossbreeding system.

[bc] Means with different superscripts differ at the $P \leq .05$ level.

The dams on which records were analyzed were born during the 7-year period from 1968 through 1974 and were the progeny of 21 Ayrshire and 16 Sahiwal sires. The calves providing records for this study were born during the 5-year period from 1973 through 1977 and were the progeny of 20 Ayrshire and 6 Sahiwal sires. Some of the sires of each breed produced dams for which data were analyzed for reproduction and lactation characters and also calves which provided data on calf survival and growth characters. All matings from which data were analyzed were by artificial insemination with semen obtained from the Central Artificial Insemination Station at Kabete. Ayrshire sires were sampled from the United Kingdom, Canada, Finland and Sweden. All Sahiwal sires that produced progeny on which records were collected for this study were produced in Kenya. It is believed that a representative sample of sires of each breed was used.

Heifers were first bred as they approached 2 years of age at a weight of about 270 kg. Calves were allowed to suckle for 1 or 2 days after birth, and were then trained to drink first colostrum and then whole milk from a pail. Male calves were castrated and all calves were weighed and given permanent identification within 36 hours of birth. The calves were bucket fed whole milk twice daily while running on pasture until they reached a weight of about 50 kg, which occurred when they were around 52 days old. From approximately 50 kg to approximately 90 kg, they were fed brewer's grains, maize bran and pelleted by-products from cereal milling in addition to good quality pasture. In general, supplementary feeding was terminated when calves reached about 90 kg, which they attained at around 122 days. The pasture provided to calves thereafter was generally of high quality.

Cows were placed in the milking herd when they produced their first calf. During lactation, they were provided supplemental feed at a level based on their production and on the condition of the pastures which they grazed. The supplemental feed consisted of brewer's grains and maize bran, and some sorghum silage was fed during dry periods when pastures were particularly short. Also, the fleshy part of sisal leaves was fed when available.

All cows were milked by hand twice daily. The day interval between milkings was approximately 11 hours and the night interval approximately 13 hours. All milking was done in the pastures in which the cows grazed. The cows were tied to posts, hobbled and given supplemental feed while they were milked. The milking site was moved at frequent intervals.

Cows had access to natural pastures with shade trees both day and night, and all animals were dipped at weekly intervals to control tick-borne diseases. The general level of husbandry would be classified as excellent. However, tsetse flies have been identified in the area and, according to the owner, a low level of trypanosomiasis is present in the herd on occasion.

All characters were analyzed by least-squares, fixed-model procedures (Harvey, 1972). The model used for all characters included the fixed effects of year of birth, month of birth, breeding group (2/3 Ayrshire - 1/3 Sahiwal or 1/3 Ayrshire - 2/3 Sahiwal) and sires within each breed. For characters relating to lactation and for calving interval, parturition number and the interaction of breeding group with year were included in the model. Sex and the interaction of breeding group with year were included in the model for the analysis of growth and viability characters. The residual mean square was used as the error term to test the significance of all effects evaluated.

2.2 RESULTS AND DISCUSSION

2.2.1 Reproductive characters

2.2.1.1 Age at first calving. The mean age at first calving was 1031 days for the 945 dams retained for milk production that were born from 1968 through 1974. The effects of the dam's year of birth were important ($P < .01$), but month of birth did not have a significant effect on calving age. Age at first calving records were available for only 22 dams born in 1968 but these were on average 140 days younger when they produced their first calf than the mean age at first calving for all the

females recorded. From 101 to 242 dams were born in each of the 6 other years and the constants for these years were all positive, ranging from 14 to 35 days, with age at first calving tending to increase slightly in each year.

The effects of individual sires were significant ($P < .01$) for both the Ayrshire and Sahiwal breeds. Thus, the additive genetic variation is large in both breeds for this character. Ayrshire-sired females averaged 23 days younger ($P < .05$) at first calving than Sahiwal-sired females (Table 1). The extent to which the older age at first calving was the result of older age at reproductive maturity in the Sahiwal-sired females is not known. However, Gregory et al (1979a) reported an older age of puberty in Sahiwal-cross females than in females of *Bos taurus* breeds, particularly in *Bos taurus* breeds that had been selected for milk production.

2.2.1.2 Calving interval. The mean calving interval for all 1661 observations was 394 days. The effects of year of calving were not important ($P > .05$), but month of calving had a significant effect on calving interval. Females calving in January, May and June had shorter than average calving intervals by 10, 9 and 14 days respectively, while those calving in September, October and November had longer than average calving intervals by 8, 8 and 15 days respectively. Females calving in the 6 other months varied from the mean calving interval of 394 days by only ± 3 days. The effects of parturition number (varying from 1 to 10) did not influence calving interval ($P > .05$).

The difference in the calving interval of their progeny was significant for Ayrshire sires ($P < .01$), but not for Sahiwal sires. The interaction of breeding group with year was important ($P < .01$) for calving interval, apparently largely because the Sahiwal-sired females had a 26-day shorter calving interval than the Ayrshire-sired females in the year with the lowest rainfall in the 4-month period after calving (188 mm), while the Sahiwal-sired females averaged a 12-day longer calving interval in the year with the second highest rainfall during the 4-month period after calving (411 mm). This result indicates that the Sahiwal breed is likely

to be better adapted than the Ayrshire breed in terms of reproductive fitness in situations of limited feed supply due to low rainfall.

Overall, Sahiwal-sired females averaged 8-day shorter calving intervals ($P < .05$) than females by Ayrshire sires (Table 1). Again, this indicates an advantage in reproductive fitness for the Sahiwal breed relative to the Ayrshire in the climatic and feed environment in which these records were made.

2.2.2 Milk production

2.2.2.1 Lactation yield. Total milk production averaged 2753 kg for the 1661 lactations included in the analysis. Year of calving had an important effect on lactation yield ($P < .01$), ranging from a low of 2437 to a high of 3017 kg during the 6½ years included in the analysis. The 2 years with lowest milk production were 1973, with an annual rainfall of 1025 mm, and 1974, with an annual rainfall of 558 mm. Milk production was highest in 1976, when rainfall was below average (836 mm). The general practice was to provide supplementary feed based on the condition of the pastures and the level of milk production. Thus, it is likely that factors other than nutritive environment associated with rainfall levels were primarily responsible for the annual variation in lactation yields.

The effects of month of calving on lactation yield were also significant. Average lactation yields associated with month of calving ranged from 2517 kg for cows calving in June to 2893 kg for cows calving in November. Cows calving during the first 7 months of the year, except those calving in March, had below average lactation yields, while among cows calving from August through December, only those calving in December had below average lactation yields.

Parturition number had a significant effect on lactation yield. For the first and second lactations, cows had below average yields, producing 2391 and 2652 kg respectively. The variation in lactation yield was small from the third to the eighth lactation, averaging 2886 kg overall. Yields declined markedly for the ninth

and tenth lactations, averaging 2582 kg. These results are consistent with most reports in the literature on the effects of age on lactation yield.

Breeding group differences were important ($P < .01$) for lactating yield. The progeny of Ayrshire sires averaged 181 kg more ($P < .01$) milk during each lactation than the progeny of Sahiwal sires (Table 1). Significant differences in lactation yield were also observed within breeds between the progeny of both the 16 Sahiwal sires and the 21 Ayrshire sires. Thus, a large amount of additive genetic variation for lactation yield is indicated for both breeds in the production environment under which these data were collected. The interaction of breeding group with year was not significant for lactation yield, however.

2.2.2.2 Annual lactation yield. Annual lactation yield averaged 2560 kg for the 1661 lactation records analyzed. After adjusting milk production to a calving interval of 365 days, the effects of year of calving were significant ($P < .01$), but the effects of month of calving were less important than they were for lactation yield. Annual lactation yields were below average for 1973 and 1974 and above average for the 4 other years. They averaged 2290 kg in 1973 and 1974, when annual rainfall over the 2-year period averaged 792 mm, and 2714 kg in 1975 and 1976, when annual rainfall over 2 years averaged 872 mm. Thus, factors other than rainfall seem to account for the significant year effects observed on annual lactation yield.

Parturition number showed similar effects on annual lactation yield as observed for full lactation yield: the first two lactations and the ninth and tenth lactations were below average, whereas the third through the eighth lactations were above average in annual lactation yield.

Significant differences in annual lactation yield were observed between the progeny of different sires within both breeds. As expected, this finding is consistent with the results on milk yield for the full lactation. The interaction of breeding group with year was not important ($P > .05$) for annual lactation yield, however.

The progeny of Ayrshire sires produced 113 kg more ($P > .01$) milk per year than the progeny of Sahiwal sires (Table 1), compared with an 181 kg difference for full lactations. The smaller difference in annual lactation yield reflects the 8-day shorter calving interval, on average, for the cows by Sahiwal sires.

2.2.3 Growth characters

2.2.3.1 Birth weight. Birth weight records were analyzed for 1680 calves born from 1973 through 1977, including 874 calves by 6 different Sahiwal sires and 806 calves by 20 Ayrshire sires. The mean birth weight for all calves was 30.0 kg. The effects of year of birth on birth weight were important ($P < .01$): average birth weights ranged from 29.3 kg in 1975, with 907 mm annual rainfall, to 31.1 kg in 1973, with 1025 mm annual rainfall. Calves born from January through May were of below average birth weight, while calves born from June through December were above average. The heaviest average birth weights were recorded for October (30.9 kg) and the lightest for April (28.7 kg). Thus, the lightest calves at birth were born during and immediately following the season when temperatures were highest.

Male calves averaged 31.0 kg at birth, 2.1 kg heavier ($P < .01$) than female calves, which averaged 28.9 kg. This difference is consistent with published results (Gregory et al, 1979b). Differences between sires within breeds were significant for birth weight. This finding is consistent with published results showing substantial additive genetic variation for birth weight. The interaction of breeding group with year of birth was not important ($P > .05$) for birth weight.

Sahiwal sires produced calves that averaged 2.9 kg heavier at birth than calves by Ayrshire sires (Table 1). Gregory et al (1979b) reported gestation lengths averaging 7 to 10 days longer for calves sired by *Bos indicus* breeds than for calves sired by *Bos taurus* breeds. The same report indicated longer average gestations for calves by Sahiwal sires than for calves by Brahman sires, another *Bos indicus* breed. It is also well documented that increased gestation length results in increased birth weight (Gregory et al, 1978c). Thus, it is likely that the

greater birth weight of calves by Sahiwal sires is associated with longer gestation length. Also, results from the Deloraine Estates data included in the current study (Chapter 3) show a large difference between the Sahiwal and Ayrshire breeds in maternal effects on birth weight: purebred calves with Ayrshire dams produced the heaviest calves at birth, followed by most types of Ayrshire cross dams and then purebred Sahiwal dams, while the effects of breed of sire on birth weight were not significant.

2.2.3.2 Average daily gain from birth to 50 kg. Overall, the calves included in this study averaged 52 days of age when they attained a weight of 50 kg. The average daily gain for all calves from birth to 50 kg was 378 g. The daily gain was significantly affected by year and month of birth ($P < .01$), but these effects did not follow a consistent pattern.

Male calves gained 13 g more ($P < .05$) per day than female calves. Differences between sires within each breed were significant for both breeds, reflecting substantial additive genetic variation in these two breeds for early postnatal growth rate when the postnatal maternal effect is removed at an early age. The interaction of breeding group with year was not significant.

Calves by Ayrshire sires gained 59 g per day faster ($P < .01$) than calves by Sahiwal sires from birth to 50 kg (Table 1). By contrast, the Sahiwal-sired cows are larger at maturity than the Ayrshire-sired cows and comparisons of the two breeds for growth characters in Chapters 3 and 4 show the Sahiwal superior in transmitted effects for growth. The higher weight gains of Ayrshire-sired calves from birth to 50 kg shown here are probably due to the fact that it is more difficult to train Sahiwal-sired calves to drink milk from a pail, according to observations of the owner and manager of Kilifi Plantations.

2.2.3.3 Average daily gain from 50 to 90 kg. The average daily gain of all calves from 50 to 90 kg was 608 g. The effects of year and month of birth were important ($P < .01$), though no consistent pattern for the effects of year of birth was evident.

The average daily gain for calves born in 1974 and 1975 was above the overall average, while the average daily gain for calves born in 1973, 1976 and 1977 was below. The average daily gain was below the overall average for calves born in April, May, September, October, November and December and above for those born in the other 6 months.

The effects of sex were not significant for average daily gain from 50 to 90 kg. As was the case for birth weight and for gain from birth to 50 kg, differences between individual sires were significant for both breeds. The interaction of breeding group with year was not significant for gain during this period.

The progeny of Ayrshire sires gained 18 g ($P < .01$) more per day than the progeny of Sahiwal sires (Table 1). The magnitude of this difference is considerably less than was observed from birth to 50 kg. It probably reflects a positive correlation with growth rate in the earlier period related to a probable competitive advantage at the feed trough because of heavier weight achieved.

2.2.3.4 Average daily gain from birth to 90 kg. The average daily gain of all calves from birth to 90 kg was 494 g. Both year and month of birth had a significant effect on average daily gain during this period. Calves born in 1973 and 1977 gained 21 and 15 g less per day, respectively, than the average for all calves. Calves born in 1974, 1975 and 1976 gained on average 12 g more per day than the overall average. Calves born in April, May, September, October, November and December gained less than the average for all calves, while calves born in the 6 other months gained more than the overall average.

The effects of sex were not significant for average daily gain from birth to 90 kg. This result is not consistent with reports in the literature, where the effects of sex on early postnatal growth rate generally approach 10%, as was observed for birth weight in the current study (Gregory et al, 1979b). However, the average daily gain from birth to 90 kg observed in this study is less than generally reported. The failure of sex effects to be expressed here in terms of average

daily gain may be the result of a lower plane of nutrition than is generally provided in conventional beef production programmes where calves are usually suckled to an age of 6 months or more.

However, the plane of nutrition provided at Kilifi Plantations was apparently adequate to allow additive genetic differences in growth rate between sires to be expressed for both breeds ($P < .05$). These results are interpreted to reflect a large amount of additive genetic variation for growth rate in both Sahiwals and Ayrshires. The interaction of breeding group with year of birth was not significant.

Average daily gain from birth to 90 kg was 45 g greater for the Ayrshire- than for the Sahiwal-sired calves (Table 1). This finding is interpreted as due to a behavioural difference, resulting in greater difficulty in training Sahiwal calves to drink from a pail. The Sahiwal-sired calves most likely had a reduced milk intake at, and immediately after, 1 or 2 days of age, relative to the Ayrshire-sired calves. A low intake of colostrum resulting in low antibody levels and a suboptimal nutritive environment during this period likely have important direct or indirect carryover effects on feed consumption when supplemental feed is restricted in a group feeding situation; thus weight gains may be reduced for an extended period.

2.2.4 Viability

2.2.4.1 Calf survival. Of all calves born, 87% lived to reach a weight of 90 kg. Neither year nor month of birth, sex, sire within breed, breeding group or the interaction of breeding group with year had important ($P > .05$) effects on calf survival.

2.2.4.2 Cow mortality. Cow mortality averaged less than 1% for the herd. There was no difference between breeding groups in this character.

2.2.5 Index of cow productivity

The characters of reproductive performance, cow and calf viability, milk production, growth and cow weight are combined in Table 2 to build up an index of the total weight of 1-year-old calf plus the liveweight equivalent of milk produced, both per cow per year and finally per 100 kg of cow maintained per year. The cow productivity index is computed as the product of cow viability (%) x calving percentage (%) x calf viability (%) x calf weight at 1 year (kg) + cow viability (%) x calving percentage (%) x lactation milked-out yield (kg)/9. The lactation milked-out yield is divided by a factor of 9 based on results by Drewry et al (1959) showing one additional unit of calf gain for nine units of additional milk consumed.

Table 2. Productivity estimates of cows by breed group, Kilifi Plantations

Character	Breed Group	
	2/3 Sahiwal - 1/3 Ayrshire	2/3 Ayrshire - 1/3 Sahiwal
Cow viability (%)	99.0	99.0
Calving percentage (%)	93.6	91.7
Calf survival (%)	85.7	87.5
Calf weight at 1 year (kg)[a]	104.7	104.7
Lactation milked-out yield (kg)	2662	2843
Productivity index[b] per cow per year (kg)	357.3	370.0
Cow weight (kg)	400	429
Productivity index[b] per 100 kg of cow maintained per year (kg)	81.2	86.2

[a] Excluding 60 kg growth from birth to 90 kg body weight when calves were artificially reared.

[b] Total weight of 1-year-old calf plus liveweight equivalent of milk produced.

This final index is the most meaningful way to compare the actual productivity of the breed types, given the level of information available. Its merit lies in the fact that it relates all the more important production characters back to the actual weight of breeding cow that has to be supported, which is closely associated with cow maintenance costs. The Ayrshire-sired cows excelled the Sahiwal-sired cows in terms of the productivity index per cow per year by 3.6% and by 6.2% per 100 kg of cow weight maintained per year.

2.2.6 General remarks

The average annual lactation yield of 2560 kg of milk for the herd on which this analysis is based is considered outstanding for a sea-level tropical environment with feed largely based on pastures. The relatively young age at first calving and the relatively short calving interval further attest to the general adaptability of both breeding groups of cattle to this climatic and feed environment. Also, the relatively high average annual lactation yield, the young age at first calving and the short calving interval indicate that a high level of husbandry has been achieved.

In a comprehensive review article on crossbreeding systems (Gregory and Cundiff, 1980), results were interpreted from crossbreeding experiments with cattle involving both dairy and beef characters to show that loss of heterosis in rotation crossbreeding systems is proportional to loss of heterozygosity. Thus, after the breed composition becomes stabilized at six generations (Dickerson, 1969 and 1973) with two-thirds of the genes from the breed of the sire and one-third from the breed of the maternal grand-sire, it is expected that two-thirds of the initial F_1 heterosis for both maternal and individual characters will be retained because two-thirds of initial F_1 heterozygosity is retained. Given the high level of heterosis reported for crosses between *Bos indicus* and *Bos taurus* cattle for both individual and maternal characters (Cartwright et al, 1974 and Koger et al, 1975), it appears the total performance of this herd benefited substantially as a result of heterosis.

Even though the results from this study show a higher level of additive genetic merit for milk production for the Ayrshire breed compared to the Sahiwal, the optimum relative contribution by the two breeds to genetic composition in this environment is not revealed because only two genetic groups are compared, one approximately 2/3 Ayrshire and 1/3 Sahiwal and the other 2/3 Sahiwal and 1/3 Ayrshire. Gregory and Cundiff (1980) have pointed out that the substantial variation between breeding groups in additive genetic composition in breed rotation crossbreeding systems, varying between two-thirds and one-third in a two-breed rotation crossbreeding system, may cause major variations in the optimum contribution by each of the breeds.

In the current evaluation, the 2/3 Ayrshire-1/3 Sahiwal breeding group appears sufficiently adaptable to the climatic and feed environment to be slightly superior to its reciprocal for most of the characters evaluated. This is reflected in the index of cow productivity as well as in the analysis of individual characters. However, the optimum additive genetic composition with these two breeds in this environment could well be some proportion of each breed between the extremes of two-thirds and one-third that characterize a two-breed rotation crossbreeding system, or perhaps even a higher proportion of Ayrshire and a correspondingly lower proportion (i.e. one-fourth) of Sahiwal may be sufficiently adaptable.

An alternative approach to rotation crossbreeding systems, that would allow the optimization of additive genetic composition based on attaining and maintaining specific percentages contributed by different breeds, may be the formation of composite breeds. This approach should allow the simultaneous use of predictable levels of heterosis with the maintenance of an optimum percentage contributed by each breed for the specific production situation. This possibility is discussed in detail in Chapter 8.

2. Pail feeding facilities, Kilifi Plantations

3. Calves at 50 to 90 kg on concentrate supplementation, Kilifi Plantations

4. Replacement heifers, Kilifi Plantations

5. 2/3 Sahiwal - 1/3 Ayrshire cow, Kilifi Plantations

6. Field milking bail, Kilifi Plantations

7. 1/3 Sahiwal - 2/3 Ayrshire cow, Kilifi Plantations

8. 1/3 Sahiwal - 1/2 Brown Swiss - 1/6 Ayrshire cow, Kilifi Plantations

9. Field milk recording, Kilifi Plantations

10. 1/6 Sahiwal - 1/2 Brown Swiss - 1/3 Ayrshire cow, Kilfi Plantations

3. DELORAINE ESTATES

3.1 BACKGROUND INFORMATION

Deloraine Estates is a privately owned ranch of about 2000 ha between Nakuru and Eldoret in Kenya's Rift Valley Province. The ranch lies at an altitude of approximately 2100 m, ranging from 1860 to 2286 m, at 0.2° latitude south. About 20% of the ranch land is classified as arable, and cereal crops are grown. On the remaining pasture land, cattle are kept for commercial beef and milk production.

Annual rainfall from 1974 through 1977 averaged 1007 mm. During this period an average of less than 35 mm of rainfall was recorded in December, January and February and an average of less than 75 mm in March, June, September and October. Average rainfall was higher in the 5 other months.

Ayrshire cattle were introduced onto the ranch in 1934 and purebred Sahiwals were introduced in 1962. Subsequently, a grading up programme has been followed for the Sahiwals by continuously backcrossing to purebred Sahiwal sires starting from a Sahiwal x Ayrshire foundation. The breeding with Ayrshire sires has been predominantly by artificial insemination, with semen obtained from the Central Artificial Insemination Station at Kabete produced by bulls imported from the United Kingdom, Canada, Sweden and Finland. The breeding with Sahiwal sires has been

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by a combination of artificial insemination and natural service. Semen from Sahiwal sires used by artificial insemination has been obtained from the Central Artificial Insemination Station at Kabete. Sahiwal sires used by natural service were bred by the National Sahiwal Stud at Naivasha, by other Sahiwal breeders in Kenya or on the ranch, and one Sahiwal sire used by natural service was imported from India. Semen used from Simmental sires was either imported from Germany or was from sires bred in Kenya. The sires used appeared to be a representative sample of their respective breeds.

The 410 cows on which records were analyzed were born from 1970 through 1974, and produced 616 lactation records and 781 calves from 1974 through 1977. Thus, the cows in this study varied from 4 to 7 years old. Discrepancies in the number of observations between total lactation yields and amount of milk extracted (Table 3) are due to the death of 39 calves and the sale of 41 straightbred male Ayrshire calves when they were about 1 week old. The breeding groups of cows included in the study were unregistered Ayrshire, Ayrshire x Sahiwal (sire breed listed first), Sahiwal x Ayrshire, pedigree Sahiwal and foundation Sahiwal (Table 3). Foundation Sahiwal were at least seven-eights Sahiwal, while pedigree Sahiwal were fifteen-sixteenths Sahiwal or more. The sire breed groups with which these females were mated were Ayrshire, Sahiwal, Simmental and a group classified as mixed which included crossbred Sahiwal x Ayrshire and bulls with sires not known. A listing of the characters analyzed and the number of records included in the analysis of each character, for each sire and dam breed, is given in Table 3. Table 4 provides information for sub-classes of breed of sire and breeding group of dam on the characters of the calves that were analyzed.

The cows were grazed on both seeded and natural pastures. When grazing was particularly limited because of drought conditions, some hay was fed. Concentrate feeds were given in limited quantities to the straightbred Ayrshire cows and to the higher producing Sahiwal - Ayrshire crossbred and straightbred Sahiwal cows. For the cows given concentrates, the objective was to provide 1 kg of concentrate feed for each 4 kg of milk extracted, but in practice the rate of concentrate

Table 3. Least-squares breeding group means and standard errors for maternal characters, Deloraine Estates

Breeding group of cow (sire listed first)	Age at first calving		Calving interval		Milk extracted[a]		Est. milk consumed by calf	Est. total milk produced	Total lactation yield[bc]		Daily lactation yield[bc]	Lactation length	Dry period length	
	N	days	N	days	N	kg	kg	kg	N	kg	kg	days	N	days
Ayrshire	189	1070[c]	201	430 ± 10.2	248	961 ± 49	1137 ± 39	2099 ± 55	302	1249[d] ± 39	3.8[d] ± 0.11	323	20[illegible]	112
Ayrshire x Sahiwal	65	1138[e]	62	382 ± 17.5	94	928 ± 54	1129 ± 42	2058 ± 60	104	1017[ef] ± 64	3.6[def] ± 0.16	263	62	124
Sahiwal x Ayrshire	92	1127[e]	87	417 ± 14.6	113	993 ± 52	1157 ± 41	2150 ± 58	126	1110[de] ± 68	4.0[de] ± 0.17	268	87	155
Sahiwal (pedigree)	44	1170[d]	24	439 ± 19.9	54	688 ± 104	1188 ± 82	1876 ± 116	53	833[f] ± 100	3.3[f] ± 0.25	240	24	198
Sahiwal (foundation)	20	1157[d]	19	407 ± 22.1	27	963 ± 155	1163 ± 122	2126 ± 173	31	927[ef] ± 159	3.5[ef] ± 0.39	264	19	166
Total or mean	410	1132	393	415	536	907	1155	2062	616	1027	3.6	272	393	151
Breed of sire of calf														
Ayrshire					105	863 ± 95	1076[d] ± 75	1940 ± 108						
Sahiwal					302	923 ± 43	1158[d] ± 34	2081 ± 48						
Simmental					61	877 ± 82	1296[e] ± 65	2173 ± 92						
Mixed					68	964 ± 92	1089[d] ± 72	2053 ± 102						
Total or mean					536	907	1155	2062						

[a] Prior to weaning of calf.

[b] Includes milk produced after calf was weaned.

[c] 41 straightbred Ayrshire male calves were sold shortly after birth; total lactation yield adjusted by 44575 kg for 302 lactations based on estimated gain of 120.8 kg per calf. Daily lactation yield was adjusted accordingly.

[def] Means having no superscript in common differ at the $P \leq .05$ level, means having no superscripts did not show a significant breeding group difference in the analysis of variance.

Table 4. Least-squares breeding group means and standard errors for calf survival and growth characters, Deloraine Estates

Breeding group of cow (sire listed first)	Calf survival		Birth weight		Weaning weight		Weaning weight of heifers kept postweaning[a]		2-year weight of heifers kept postweaning[a]
	N	%	N	kg	N	kg	N	kg	kg
Ayrshire	357	83 ± 3.8	170	32.0[b] ± 0.87	256	175 ± 4.8	87	169[b] ± 9.3	312 ± 10.4
Ayrshire x Sahiwal	129	88 ± 3.8	73	29.5[ce] ± 0.86	106	174 ± 5.2	41	196[c] ± 9.5	328 ± 10.7
Sahiwal x Ayrshire	157	87 ± 3.7	100	30.3[be] ± 0.88	127	176 ± 5.1	33	172[bc] ± 10.1	325 ± 11.4
Sahiwal (pedigree)	95	99 ± 9.2	52	24.7[d] ± 1.56	79	174 ± 9.5	34	155[b] ± 10.9	318 ± 12.2
Sahiwal (foundation)	43	91 ± 13.0	27	23.2[d] ± 2.13	29	154 ± 14.9			
Total or mean	781	90	422	28.0	597	171	195	173	320
Breed of sire of calf									
Ayrshire	171	93 ± 6.5	93	25.7 ± 1.92	109	164 ± 8.8	22	151[b] ± 11.4	295[b] ± 12.8
Sahiwal	433	84 ± 3.2	214	28.4 ± 0.67	347	171 ± 4.0	130	166[bd] ± 5.2	326[c] ± 5.8
Simmental	77	90 ± 7.1	47	28.8 ± 1.33	67	182 ± 7.9	34	178[cd] ± 8.2	341[c] ± 9.2
Mixed	100	91 ± 7.2	68	28.9 ± 1.38	74	166 ± 9.1	9	197[c] ± 13.7	320[bc] ± 15.4
Total or mean	781	90	422	28.0	597	171	195	173	320

[a] 30 pedigree and 4 foundation Sahiwal heifers were combined for the analysis of these two characters.

[bcde] Means having no superscript letter in common differ at the $P \leq .05$ level; means having no superscripts did not show a significant breeding group difference in the analysis of variance.

feeding tended to be lower. Lower producing Sahiwal-Ayrshire crossbred cows and straightbred Sahiwal cows did not receive any concentrates. Both the owner and the manager stated that the Ayrshire cows received preferential treatment relative to the Ayrshire-Sahiwal crosses and the purebred Sahiwals: they had access to pastures that were considered superior and received hay earlier and in larger quantities during periods of drought. When the three breeding groups of cows were observed, the conditions of their pastures appeared similar. However, the Sahiwal cows normally graze pastures with steeper slopes that are thought to produce a high proportion of vegetation with a relatively low nutritional value. The purebred Ayrshire cows were the only group receiving supplementary feed in the form of hay at the time the herd was visited. The results of this study should be interpreted in light of the preferential treatment received by the straightbred Ayrshires. The owner stated that Sahiwals were introduced onto the ranch because of their ability to perform under conditions of nutritional and climatic stress.

Cows were hand milked twice daily while the calves suckled, with the intention of allowing the calves to consume about one-half of the milk produced. Calves were separated from their dams between milkings after they were 4 days old; they had access to pasture continuously and were weaned at 8 months. When pastures were poor because of drought conditions calves were offered hay of the highest quality available. The cows were dipped two times a week to control tick-borne diseases.

All characters were analyzed by least-squares fixed-model procedures (Harvey, 1972). The model used included the fixed effects of year of birth, month of birth and breeding group of cow for all characters. For most of the cow characters, including milk extracted, estimated milk consumed by calf and estimated total milk produced, and for characters evaluated in the calf, the model also included the effects of breed of sire, parturition number, sex of calf, and the interactions of breed of sire with breeding group of dam, breed of sire with year and breeding group of dam with year. The specific factors included in the model used will be evident when results are presented for each character analyzed. The residual mean square was used as the error term to test the significance of all

differences evaluated. Linear contrasts of least-squares means were computed to determine the significance of differences between breeding groups of cows and breeds of sires for all characters where the difference among breeding groups was significant in the analysis of variance. More comparisons were made using the least-squares means than there are independent degrees of freedom for the characters where the breeding group of cow or breed of sire differences were significant in the analysis of variance. Therefore, all of the comparisons are not independent and the error rate over the entire set of comparisons may be different from that indicated by the level of probability. Tests of significance associated with the linear contrasts, although not independent, can be taken as guides as to whether the observed values could have occurred by chance.

3.2 RESULTS AND DISCUSSION

3.2.1 Reproductive characters

3.2.1.1 Age at first calving. The mean age at first calving for all the 410 cows was 1132 days. The effects of year of birth of cow were not important ($P > .05$), but month of birth had a significant effect. Cows that were calved in November-December, January-February and March-April produced their first calves when they were 8, 23 and 18 days younger, respectively, than the mean age at first calving for the whole sample, while cows that were calved in May-June, July-August and September-October were, respectively, 35, 14 and 1 days older at first calving than the overall average.

Differences between breeding groups in age at first calving were also important ($P < .01$). The Ayrshire cows produced their first calves when they were 62 days younger than the overall average and were significantly younger at first calving than all other breed groups; the Sahiwal-Ayrshire reciprocal cross cows were significantly younger at first calving than both breed groups of Sahiwal cows, while the two groups of Sahiwal cows did not differ in age at first calving (Table 3). The earlier first calving age of the purebred Ayrshire cows was most

likely the result of earlier reproductive maturity. As shown by Gregory et al (1979a), *Bos taurus* breeds, particularly those that have been selected for milk production, mature at a much younger age than *Bos indicus* breeds.

3.2.1.2 Calving interval. The mean calving interval for the 393 records analyzed was 415 days. The effect of year of calving was important ($P < .01$) though the pattern was not consistent: compared with the overall average, calving intervals averaged 1 day shorter in 1974, 54 days longer in 1975, 7 days longer in 1976 and 60 days shorter in 1977. The month of calving did not significantly affect calving interval, but the parturition number did ($P < .05$). Calving intervals averaged, respectively, 13 and 22 days longer than the overall mean for the first and second parturitions, and 29 and 5 days shorter for the third and fourth parturitions. This is consistent with numerous reports in the literature which show longer calving intervals for young cows that still have a nutritive requirement for growth.

There was not a significant difference in calving interval between breeding groups of cows, nor did the interaction of cow breeding group with year have a significant effect on calving interval. However, the calving interval of the straightbred Ayrshire cows was among the longest, even though they were given preferential feeding.

3.2.2 Milk production

To provide an estimate of total milk produced, milk consumption by each calf was estimated by assuming that 9 kg of milk were required to produce 1 kg of calf weight gain, based on results reported by Drewry et al (1959). Thus, calf weight gain during the suckling period was multiplied by 9 to obtain an estimate of milk consumed by each calf. Figures for total lactation yield and daily milk yield (Table 3) are based on the total milk extracted both before and after weaning.

3.2.2.1 Milk extracted. For 536 lactations, an average of 907 kg of milk was extracted during the four years. The effects of year of calving on milk extracted

were important ($P < .01$), with a major increase in milk extracted during the four years that data were recorded: from 691 kg in 1974 to 815 kg in 1975, 1041 kg in 1976 and 1079 kg in 1977. The effects of month of calving on milk extracted were also significant: an average of 941 kg of milk was extracted from cows calving in March-April and 1048 kg from those calving in May-June, while milk extracted from cows calving during the other 8 months was below the mean for this character. Parturition number also had a major effect on milk extracted ($P < .01$): an average of 745 kg was extracted from all first parturitions, 935 kg from the second, 1016 kg from the third and 930 kg from the fourth parturitions. No explanation is apparent for the higher level of milk extracted in the third parturition than in the fourth; a plateau would normally be expected, starting with the second parturition.

Neither sex of calf nor sire breed nor cow breeding group had a significant effect on milk extracted. The interactions of sire breed with year and cow breeding group with year also failed to have a significant influence. However, the interaction of sire breed with cow breeding group was significant.

3.2.2.2 Estimated milk consumed by calf. Based on weight gains before weaning, an estimated average of 1155 kg of milk was consumed by all calves (Drewry et al, 1959). The year of calving had a major effect ($P < .01$) on the estimated milk consumed by calves. Based on weight gains during the suckling period, calves consumed on average an estimated 374 kg more than the overall mean in 1974, and 129, 62 and 183 kg less than the overall mean in 1975, 1976 and 1977 respectively. Month of birth also significantly influenced estimated milk consumption by calves: calves born from June through December were estimated to consume on average 236 kg less milk before weaning than calves born from January through June. Parturition number did not have a significant influence on estimated calf milk consumption, but it was estimated that male calves consumed 109 kg more ($P < .01$) milk than female calves during the suckling period.

Calves by Simmental sires were estimated to consume significantly more

milk than calves by the three other sire breeds (Table 3). Differences between cow breeding groups and the interaction of cow breeding group with year were not significant, but the interactions of sire breed with cow breeding group and sire breed with year were significant. The significant interaction of sire and cow breeds reflects heterosis effects on preweaning gain because calf milk consumption estimates were based on weight gains. A major shift in rank among sire breeds in terms of estimated calf milk consumption was evident during the four years.

3.2.2.3 Estimated total milk production. Based on the milk extracted and the estimated milk consumed by calves, the estimated total milk produced from birth to weaning averaged 2062 kg for 536 cows. Estimated total milk production was 2220 kg in 1974, 1841 kg in 1975, 2134 kg in 1976 and 2051 kg in 1977 ($P < .05$). Month of calving had a significant effect on estimated total milk produced: cows calving from January through June averaged 345 kg more milk than cows calving from July through December, reflecting greater weight gains for calves born during the first half of the year. Estimated milk production during first lactations averaged 187 kg less ($P < .01$) than the mean production for four lactations. This result is consistent with numerous reports in the literature that show that milk production increases with age until maturity.

Cows suckling male calves were estimated to produce 126 kg more milk ($P < .01$) than cows suckling females. This is primarily due to the greater estimated milk consumption by male calves, based on their greater weight gains. The interaction of cow breeding group with year was not significant for estimated total milk produced, but the interactions of sire breed with cow breeding group and of sire breed with year were significant. The significant interaction of sire breed with cow breeding group is strongly influenced by the estimated milk consumed by calves, based on calf weight gains and thus reflecting heterosis effects on preweaning growth rate. Neither breed of sire nor breeding group of dam, taken alone, had a significant influence on estimated total milk produced (Table 3).

3.2.2.4 Total lactation yield. Total lactation yield included all milk extracted

before and after weaning until the cow was dried off prior to subsequent parturition. Of the 616 cows for which data were analyzed, 80 did not suckle calves because 39 calves died and 41 were sold out, as previously mentioned. The total lactation yield for straightbred Ayrshire cows was adjusted (Drewry et al, 1959) to account for the 41 Ayrshire male calves sold out shortly after birth (Table 3).

The adjusted total lactation yield for the 616 lactations recorded during the 4 years was 1027 kg. The year of calving affected total lactation yields significantly ($P < .01$): yields increased progressively during the 4-year period from 721 kg in 1974 to 994 kg in 1975, 1180 kg in 1976 and 1332 kg in 1977. Total lactation yields averaged 350 kg less ($P < .05$) for cows calving in January-February, July-August and September-October than for those calving in the other 6 months, and were highest for cows calving in May-June (1190 kg). Parturition number significantly influenced lactation yield: first lactation yields averaged 913 kg, second averaged 1094 kg, third averaged 1166 kg and fourth averaged 1054 kg, which is consistent with the effects observed on milk extracted before weaning and on estimated total milk production.

Cow breeding groups differed significantly in terms of lactation yield (Table 3). Ayrshire cows averaged significantly higher total lactation yields than all other breeding groups except Sahiwal x Ayrshire crosses. However, this value for Ayrshire cows is biased upward because straightbred Ayrshire cows received preferential feeding. Sahiwal x Ayrshire crosses averaged significantly higher total lactation yields than pedigree Sahiwal cows, but not Ayrshire x Sahiwals or foundation Sahiwals (Table 3). The interaction of cow breeding group with year was not significant.

3.2.2.5 Daily milk yield. Daily milk yield is an average of the amount of milk extracted every day over a full lactation; for the 616 lactations included in the analysis the daily yield averaged 3.6 kg. The daily milk yield of Ayrshire cows was adjusted to account for the 41 Ayrshire male calves disposed of shortly after birth. Daily milk yield was significantly influenced by year, month of birth of calf and

parturition number, with similar effects in terms of magnitude and direction as those for total lactation yield. In addition, the interaction of cow breeding group with year was significant for daily milk yield as a result of the change in rank of cow breeding groups in different years.

Cow breeding groups differed significantly in daily milk yield (Table 3). Straightbred Ayrshire cows were significantly superior to all other breeding groups in this character except Sahiwal x Ayrshire and Ayrshire x Sahiwal crosses but this difference reflects a certain amount of bias due to preferential treatment. Sahiwal x Ayrshire crosses had significantly higher daily milk yields than pedigree Sahiwals, but not Ayrshire x Sahiwal crosses or foundation Sahiwal cows (Table 3).

3.2.2.6 Lactation length. Lactation length averaged 272 days for the 616 lactations included in the study. For cows calving in 1974, the average lactation was 55 days shorter than that of cows calving in 1976. For cows calving in July-August, the average lactation was 17 days shorter than the overall average, while the lactations of cows calving in November-December and January-February averaged 11 and 7 days longer, respectively, than the overall mean. Lactation lengths in the other months did not deviate appreciably from the mean. Lactation lengths following the fourth parturition averaged 20 days shorter than the mean lactation length, while lactations for all other parturitions were on average longer than the overall mean. Straightbred Ayrshire cows averaged the longest lactations (323 days) and pedigree Sahiwals the shortest (240 days).

3.2.2.7 Length of dry period. The length of dry period was recorded after 393 lactations and averaged 151 days (Table 3). Dry periods averaged 109 days shorter in 1977 than in 1974 and 97 days shorter in 1977 than in 1975. The dry periods averaged 148 days for cows calving in September-October and 133 days for cows calving in November-December, and averaged longer than 151 days for cows calving in all other months. Dry periods averaged 132 days after the third parturition and 167 days after the fourth. Straightbred Ayrshire cows averaged the

shortest dry periods (112 days), while pedigree Sahiwals averaged the longest (198 days).

3.2.3 Growth characters

3.2.3.1 Birth weight. The average birth weight of 422 calves born from 1974 through 1977 was 28.0 kg (Table 4). Year of birth was not a significant influence, but calves born from January through August averaged 2 kg heavier ($P < .01$) than calves born from September through December (28.6 vs 26.6 kg). Calves born from first parturitions averaged 1.2 kg lighter ($P < .05$) than the overall mean, and male calves averaged 1.3 kg heavier ($P < .01$) than females. The interactions of breed of sire with year and breeding group of cow with year were significant for birth weight. However, the interaction of breed of sire with breeding group of cow was not significant.

The effects of breed of sire on birth weight were not significant (Table 4). However, straightbred Ayrshire cows produced calves that were significantly heavier than calves produced by Ayrshire x Sahiwal cross cows, pedigree Sahiwal cows or foundation Sahiwal cows, but not Sahiwal x Ayrshire cross cows (Table 4). Ayrshire x Sahiwal cross and Sahiwal x Ayrshire cross cows produced calves that were significantly heavier than pedigree Sahiwal or foundation Sahiwal cows. The average birth weights for different cow breeding groups compared with the averages for different sire breeds show major differences in maternal effects on birth weight between the Ayrshire and Sahiwal breeds (Table 4).

3.2.3.2 Weaning weight. A mean weaning weight of 171 kg was calculated, adjusted to 8 months of age, for the 597 calves on which data were recorded (Table 4). Average weaning weights were 206 kg for calves born in 1974, 162 kg for 1975, 163 kg for 1976 and 151 kg for 1977 ($P < .01$), showing a marked decline over the four years. This decline may be largely due to an increase in the amount of milk extracted during this period. Calves born from January through June weighed 26 kg more ($P < .01$) at weaning than calves born from July through December (184 vs

158 kg). Parturition number did not have a significant effect on weaning weight. Male calves averaged 18 kg heavier ($P < .01$) at weaning than female calves: this difference of 10% in favour of the males is consistent with reports in the literature of situations where all the milk produced is consumed by calves (Gregory et al, 1979b). The interaction of cow breeding group with year was significant, but the interaction of breed of sire with year was not.

Neither breed of sire nor breeding group of cow had a significant effect on calf weaning weight (Table 4). This result may indicate that the amount of milk extracted from a cow was likely determined by the general appearance of her calf, thus limiting the opportunity for the transmitted effects of breed of sire or the transmitted and maternal effects of breeding group of cow to be expressed. The interaction of breed of sire with breeding group of cow was significant, however, reflecting the importance of heterosis on this character.

3.2.3.3 Postweaning growth of heifers up to 2 years. The ranch managers retained 195 heifers until they were 2 years old, the offspring of all five cow breeding groups and all sire breeds. The heifers kept after weaning were a representative sample of all heifers produced in each breeding group because no sequential selection was practised for growth rate. These provide a basis for characterizing the different cow breeding groups and sire breeds in terms of postweaning growth. Only heifers born in 1974, 1975 and 1976 were included in this analysis because the heifers born in 1977 were not yet 2 years old when the data were analyzed. These heifers were all grazed together on both seeded and natural pastures after weaning. Their average adjusted 8-months weaning weight was 173 kg.

For the heifers kept after weaning, the effects of year of birth on weaning weight followed the same pattern of decline with years as observed for all calves ($P < .01$): weaning weights averaged 192 kg for heifers born in 1974, 166 kg for those born in 1975 and 161 kg for those born in 1976. The pattern was similar for the effects of month of birth on weaning weight ($P < .01$): heifer calves born from January through June weighed on average 32

kg more at weaning than calves born from July through December. Parturition number did not have a significant effect on the weaning weight of this group, however. The interaction of sire breed with cow breeding group was significant for weaning weight, reflecting the effect of heterosis on this character. For heifers kept after weaning, both breed of sire and dam breeding group had a significant effect on weaning weight (Table 4). The heifer progeny of pedigree and foundation Sahiwal dams were combined in this analysis. The progeny of Ayrshire x Sahiwal cross cows were significantly heavier than the progeny of straightbred Ayrshire and purebred Sahiwal dams but not Sahiwal x Ayrshire cross dams (Table 4). The heifer progeny of straightbred Ayrshire and purebred Sahiwal dams did not differ significantly ($P > .05$).

Among heifers kept after weaning, the progeny of Simmental sires were significantly heavier at weaning than the progeny of Ayrshire, but not Sahiwal sires. The progeny of mixed breed sires were significantly heavier at weaning than the progeny of Ayrshire and Sahiwal, but not Simmental sires (Table 4).

The mean weight of the 195 heifers at 2 years was 320 kg. Year of birth had a significant effect on weight at 2 years: heifers born in 1976 averaged 34 kg heavier than heifers born in 1974 or 1975. The effects of month of birth observed in terms of weaning weight were not observed at 2 years ($P > .05$), nor did parturition number influence 2-year weights.

The effects of sire breed, but not breeding group of cow, were significant (Table 4). The progeny of Sahiwal and Simmental sires did not differ ($P > .05$) significantly; both were significantly heavier than the progeny of Ayrshire, but not mixed breed sires. The difference between the progeny of Ayrshire and mixed breed sires was not significant. The interaction of sire breed with breeding group of cow was significant, indicating the importance of heterosis on this character.

3.2.4 Viability

3.2.4.1 Calf survival. Of the 781 calves born in all breed groups from 1974 through 1977, 90% survived until weaning at 8 months. Year of birth had a significant effect on calf survival: among calves born in 1976, 6% fewer survived until weaning than the overall average. Calf survival rate was not influenced ($P > .05$) by month of birth, parturition number, breed of sire, breeding group of cow or the interaction of sire breed with cow breed.

3.2.4.2 Cow mortality. Ayrshire and crossbred Ayrshire-Sahiwal cows were normally culled at 10 years. However, in order to increase the number of purebred Sahiwal females more rapidly, these cows were normally not culled until 12 years. As indicated in Table 5, the mortality rate for Sahiwal cows was higher than for Ayrshire or Ayrshire-Sahiwal reciprocal cross cows (9 vs 3%). Cows born from 1971 through 1973 were only 5 to 7 years old in 1978, so the older age at which Sahiwal cows were culled did not contribute to their higher mortality rate. According to the owner, the straightbred Sahiwal cows were grazed in a pasture adjacent to the ranch boundary where they contracted East Coast fever on four occasions from the neighbours' cattle. Thus, their higher mortality may be interpreted as due to chance.

Table 5. Cow mortality, Deloraine Estates

Breeding group[a]	Number of cows born 1971-1973 entering breeding herd	Number of cow-years[b]	Number of cow deaths[b]	% deaths per year
Sahiwal	39	121	11	9
A x S and S x A	77	245	7	3
Ayrshire	90	326	10	3

[a] A = Ayrshire, S = Sahiwal, sire breed listed fire

[b] Based on calculations through 1978.

3.2.5 Index of cow productivity

The characters of reproductive performance, cow and calf viability, milk production and growth are combined in Table 6 to build up an index f the total weight of 1-year-old calf plus the liveweight equivalent of milk produced per cow per year. The cow productivity index is computed as the product of cow viability (%) x calving percentage (%) x calf viability (%) x calf weight at 1 year (kg) + cow viability (%) x calving percentage (%) x lactation milked out yield (kg)/9. The 1/2 Ayrshire - 1/2 Sahiwal breeding group had a 3.8% greater cow productivity index than the straightbred Ayrshire cows, even though the straightbred Ayrshire cows received preferential treatment.

Table 6. Productivity estimates of cows by breed group, Deloraine Estates

Character	Sahiwal	1/2 Ayrshire - 1/2 Sahiwal	Ayrshire
Cow survival (%)	91.0	97.0	97.0
Calving percentage (%)	86.3	91.4	84.9
Calf survival (%)	95.0	87.5	83.0
Calf weight at 1 year (kg)	200.9	208.8	208.8
Lactation milked-out yield (kg)	880	1064	1249
Productivity index[a] per cow per year (kg)	226.7	266.8	256.9

[a] Total weight of 1-year-old calf plus liveweight equivalent of milk produced.

3.2.6 General remarks

The preferential treatment received by the purebred Ayrshire cows in this study is highly relevant to interpretation of the results reported. The owner of Deloraine Estates considered preferential treatment necessary for Ayrshire cows to function effectively in the given climatic and nutritive environment. The Ayrshire

breed is clearly superior to the Sahiwal breed in transmitted effects for milk production characters (Table 3) provided that the environmental conditions are brought up to the level necessary for the Ayrshires to express their superiority. Their greater genetic potential for milk production is probably associated with a lower level of adaptability to marginal nutritive and climatic conditions. The extent to which superior nutritive environment can compensate for the effects of climatic stress is not known, but there is likely to be a relationship between nutritive and climatic environment which needs to be considered when assessing the adaptability to the total environment of different cattle populations with different production characteristics. Presumably the better than average nutritive environment provided to the Ayrshire cows at Deloraine may have resulted in their greater tolerance to climatic stress. Some modification of the natural nutritive environment is probably necessary in the tropics if Ayrshires are to achieve satisfactory total performance, and in particular satisfactory reproductive performance.

The general appearance of the purebred Ayrshire cows at Deloraine Estates was less favourable than that of the Ayrshire-Sahiwal reciprocal crosses or the purebred Sahiwal cows when observed in January 1980 during a period of poor grazing conditions and relatively high temperatures. This subjective evaluation was based on sleekness of haircoat and differences in whole body composition. For the characters relating to milk production, however, the purebred Sahiwals revealed some deficiencies, as shown in Table 3. The Sahiwal-Ayrshire crossbred cows seem to provide a more favourable additive genetic composition for milk production in the given nutritive and climatic environment.

When variable amounts of milk are extracted from cows in addition to the milk consumed by calves, it is not possible to characterize different breeding groups effectively for maternal ability based on the weaning weight of calves. The results presented in Table 4 do not show a significant difference between either breeding group of cow or breed of sire for calf weaning weight. This suggests that the amount of milk extracted from each cow may have been determined by the ranch managers according to the appearance of the calf. Such a practice would tend to

minimize the expression of genetic differences. Results on breed of sire effects presented in Table 4 for weight of 2-year-old heifers show the Sahiwal breed to be superior to the Ayrshire in transmitted effects for growth in the environment under which these data were collected.

11. Sahiwal cow, Deloraine Estates

12. 1/2 Sahiwal - 1/2 Ayrshire milking herd, Deloraine Estates

13. Ayrshire cow, poorly adapted, Deloraine Estates

4. CEDARVALE FARMS

4.1 BACKGROUND INFORMATION

Cedarvale Farms is a privately owned ranch of 3000 ha in Kenya's Rift Valley Province near Nanyuki. The ranch is located on the equator in a lower-potential area of the Kenyan highlands. Elevation is about 2000 m, and annual rainfall from 1974 through 1977 averaged 682 mm, falling mainly from April through June. A herd of purebred Sahiwals is kept for the sale of breeding stock, and Sahiwal and Ayrshire crossbreds in varying proportions are kept for meat and milk production.

The records of 435 cows were analyzed, born from 1965 through 1974, including 401 lactation records kept from 1975 through 1977 and information on 799 calves produced from 1975 through 1977. The cow breeding groups on which data were analyzed included 3/4 Ayrshire - 1/4 Sahiwal (breed of sire listed first), Ayrshire x Sahiwal, Sahiwal x Ayrshire, 3/4 Sahiwal - 1/4 Ayrshire, purebred Sahiwal and Sahiwal x Friesian. These females were mated to purebred Ayrshire and purebred Sahiwal sires to produce the calves on which records were analyzed. A list of the characters analyzed and the number of records included in the analysis of each character is given in Tables 7 and 8. Table 9 provides information on calf survival and weaning weight by breed of sire - breeding group of dam subclass.

The purebred Sahiwal population is based on the purchase of a small number

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of pedigree Sahiwal cows in 1962. Sahiwal sires have been used at Cedarvale Farms since 1952 by topcrossing them on predominantly Ayrshire cows, both by artificial insemination and natural service. Sahiwal sires have been bought in from the National Sahiwal Stud at Naivasha and from other Sahiwal breeders in Kenya, but a high percentage has been produced in the ranch's own pedigree Sahiwal herd. Semen from Sahiwal sires is collected and processed at the farm for artificial insemination and Sahiwal semen is also obtained from the Central Artificial Insemination Station at Kabete. Ayrshire sires have been used by artificial insemination, with semen obtained from the Central Artificial Insemination Station produced by bulls imported from the United Kingdom, Canada, Sweden and Finland. Breeding is carried out throughout the year except from April 15 until June 1. The sires used appear to be a representative sample of their respective breeds.

The cows are grazed on both seeded and natural pastures during the day and are confined with no grazing at night. When grazing is particularly limited because of drought conditions some hay is fed, but not concentrates. Cows are dipped either once or twice a week to control tick-borne diseases.

Cows are hand milked twice daily. For lactation records, cows were divided into two groups according to the milking system practised: those which were hand milked only with no suckling, and those which were hand milked either with or without suckling by the dam's own calf and later suckled by a variety of calves when the milk extracted dropped to the level where hand milking became economically unattractive. Thus, cows producing at a higher level were hand milked only and cows producing milk at lower levels were partially hand milked and partially suckled. In all, 288 lactations were recorded under the first milking system and 113 under the second. All pedigree Sahiwal cows suckled their own calves for 30 to 60 seconds prior to milking in order to stimulate the let-down of milk. After as much milk as possible was extracted by hand, the calf was allowed to return to its dam to suckle. Thus, pedigree Sahiwal calves probably received highly variable amounts of milk, depending on the level of let-down of their dams with hand milking.

Calves were reared under three systems: either their dam was primarily milked (and possibly later multiple suckled) and the calf suckled other cows throughout, or the dam suckled her own calf and others, or the dam suckled her own calf primarily, and suckled others or was hand milked a little. Out of 799 calves included in the analysis, 397 were reared under the first system, 271 under the second and 131 under the third.

All traits were analyzed by least-squares fixed-model procedures (Harvey, 1972). As appropriate for each character involved, the model was varied in regard to the factors included. However, the fixed effects of year and month of birth of cow, year and month of birth of calf, parturition number, breed of sire of cow and of calf, breed of dam of cow and of calf, milking system of cow, rearing system of calf, sires within breed of sire for each breed and interactions involving breed of sire of cow, breed of dam of cow, milking system of cow, rearing system of calf and year of birth were included in the model for the analysis of most characters. The means presented for breeding group of cow (Table 7) were computed from the interactions of the breed of sire of cow and breed of dam of cow. The specific factors included in the model for the analysis of each character will be evident when results are presented and discussed for the characters shown in Tables 7 and 8. Linear contrasts of least-squares breeding group means were computed to determine the significance of differences between breeding groups of cows (Table 7) and calf characters within breeding groups of dams (Table 8) for all characters for which the difference among breeding groups was significant in the analysis of variance. In each case where the breeding group of cow was significant for characters of the cow and the breeding group of dam was significant for characters of the calf, more comparisons were made using the least-squares means than the number of independent degrees of freedom. Therefore, all of the comparisons are not independent and the error rate over the entire set of comparisons may be different from that indicated by the level of probability. Tests of significance associated with the linear contrasts, although not independent, can be taken as guides as to whether the observed values could have occurred by chance. The residual mean square was used as the error term to test the significance of all

Table 7. Least-squares breeding group means and standard errors for maternal characters, Cedervale Farms

Breeding group of cow	Age at first calving		Calving interval		Lactation			
					total yield	length	daily yield	
	N	days	N	days	N	kg	days	kg
3/4 Ayrshire - 1/4 Sahiwal	148	$1071^{a} \pm 10.4$	191	$453^{a} \pm 12.3$	148	$1674^{ad} \pm 138$	197 ± 17	$7.4^{a} \pm 0.37$
Ayrshire x Sahiwal	40	$1062^{a} \pm 15.0$	105	$445^{a} \pm 14.6$	37	$1952^{ac} \pm 193$	220 ± 24	$7.8^{a} \pm 0.51$
Sahiwal x Ayrshire	28	$1105^{ab} \pm 18.9$	122	$386^{bc} \pm 15.5$	27	$1417^{af} \pm 266$	186 ± 33	$7.2^{a} \pm 0.71$
3/4 Sahiwal - 1/4 Ayrshire	150	$1066^{a} \pm 12.3$	143	$396^{bc} \pm 12.6$	139	$1464^{df} \pm 141$	191 ± 18	$7.2^{a} \pm 0.38$
Purebred Sahiwal	45	$1116^{b} \pm 15.2$	94	$450^{a} \pm 14.3$	25	$956^{bef} \pm 261$	143 ± 33	$5.2^{b} \pm 0.69$
Sahiwal x crossbred Friesian	24	$1056^{a} \pm 19.7$	62	$412^{ac} \pm 17.7$	25	$1605^{af} \pm 209$	190 ± 26	$8.2^{a} \pm 0.55$
Total or mean	435	1079	717	424	401	1511	188	7.2

abcdef Means having no superscript in common differ at the $P \leq .05$ level; those with no superscripts did not show a significant breeding group difference in the analysis of variance.

differences evaluated.

4.2 RESULTS AND DISCUSSION

4.2.1 Reproductive characters

4.2.1.1 Age at first calving. The mean age at first calving was 1079 days for 435 cows from six breeding groups, born from 1965 through 1974. The effects of cow's year of birth were significant for this character, though the pattern was not consistent. The youngest average age at first calving was 1035 days for cows born in 1970,while the oldest age at first calving was 1142 days for cows born in 1972. Cow's month of birth also had a significant effect on age at first calving. Cows born from July through December were 108 days younger on average at first calving than cows born from January through June.

Cows with Sahiwal sires did not differ ($P > .05$) in terms of age at first calving from cows with Ayrshire sires. Breeding groups of cows differed significantly, however (Table 7). The purebred Sahiwal cows were significantly older (1116 days) on average at first calving than all other breeding groups except Sahiwal x Ayrshire crosses. The other breeding groups did not differ ($P > .05$) in this character.

4.2.1.2 Calving interval. The mean calving interval was 424 days for the six breeding groups of cows, based on 717 observations. Year of calving (1968 through 1975) influenced calving interval significantly ($P < .01$), though the pattern was not consistent. The shortest average calving interval of 377 days was for cows calving in 1975, while the longest (485 days) was for cows calving in 1971. Neither month of calving nor parturition number had a significant effect on calving interval.

Breed of sire of cow also significantly influenced calving interval. Cows by Sahiwal sires averaged a 26-day shorter calving interval (411 vs 437 days) than

Table 8. Least-squares breeding group means and standard errors for calf survival and growth characters, Cedarvale Farms

	Calf survival		Weaning weight		Steer weights adjusted to constant age of:			
	N	%	N	kg	N	27 months kg	30 months kg	36 months kg
Breeding group of cow								
3/4 Ayrshire - 1/4 Sahiwal	220	90[a] ± 6.4	131	171±10.7	25	351 ±18.3	395± 20.6	451 ± 23.5
Ayrshire x Sahiwal and reciprocal	119	86[a] ± 4.3	52	161 ± 8.6	34	354 ± 8.3	402 ± 9.4	471 ± 11.0
3/4 Sahiwal - 1/4 Ayrshire	292	80[a] ± 3.5	127	153 ± 8.0	51	351 ± 7.6	398 ± 8.6	457 ± 9.9
Purebred Sahiwal	84	56[b] ± 6.8	31	160 ±16.5				
Sahiwal x crossbred Friesian	84	85[a] ± 6.6	43	171 ±10.8	17	365 ±12.1	412± 13.6	491 ±16.2
Sahiwal x Friesian					14	354 ±15.3	403± 17.4	468 ±20.2
Total or mean	799	79	384	163	141	355	402	468
Breed of sire[c]								
Ayrshire	365	79 ± 3.9	165	164 ± 9.5	67	322[a] ± 11.0	369[a] ± 12.6	429[a] ± 14.6
Sahiwal	434	83 ± 3.7	219	162 ± 6.5	74	386[b] ± 6.4	434[b] ± 7.2	505[b] ± 8.4
Total or mean	799	80	384	163	141	354	402	467

[ab] Means having no superscripts in common differ at the $P \leq .05$ level; those with no superscripts did not show a significant breeding group difference in the analysis of variance.

[c] Ayrshire sires were not mated to Sahiwal dams.

cows by Ayrshire sires. The difference between the 4 Ayrshire sires was not significant in terms of the calving interval of the progeny, but the difference between the progeny of the 10 Sahiwal sires was significant for calving interval.

The difference between breeding groups of cows was also significant. Purebred Sahiwal, Ayrshire x Sahiwal and 3/4 Ayrshire - 1/4 Sahiwal cows had significantly longer calving intervals than Sahiwal x Ayrshire and 3/4 Sahiwal - 1/4 Ayrshire cows, but Sahiwal x Ayrshire, 3/4 Sahiwal - 1/4 Ayrshire and Sahiwal x Friesian cows did not differ significantly ($P > .05$) in terms of calving interval (Table 7).

4.2.2 Milk Production

4.2.2.1 Lactation yield. From 1975 through 1977, 401 lactations were recorded. The average lactation yield was 1511 kg for the six breeding groups of cows. The effects of year of calving on lactation yield were important ($P < .01$): there was a marked decline in lactation yield over the three years, with yields averaging 709 kg more in 1975 than in 1977. The effects of month of calving on lactation yield were also significant: cows calving in January-February and March-April produced on average 409 kg more milk per lactation than cows calving during the last eight months of the year. Also, the effects of parturition number on lactation yield were important ($P < .01$): yields following the first and second parturition averaged 597 and 8 kg less, respectively, than the average of the six parturitions included in the analysis. For unknown reasons, lactation yields following the fourth parturition also averaged 118 kg less than the overall average. Lactation yields of cows under the first milking system averaged 1416 kg greater than those of cows under the second milking system (see section 4.1).

Differences between sire breeds of cows were significant for lactation yield: the progeny of Ayrshire sires produced 602 kg more milk on average per lactation than the progeny of Sahiwal sires. Differences between sires within breed of sire were not significant for either Ayrshires or Sahiwals, however. None of the

interactions involving year or milking system were significant for lactation yield.

Differences between breeding groups of cows were also significant (Table 7). The 3/4 Ayrshire - 1/4 Sahiwal cows produced significantly more milk than the purebred Sahiwal cows, and the Ayrshire x Sahiwal cows produced significantly more milk than 3/4 Sahiwal - 1/4 Ayrshire or purebred Sahiwals. Sahiwal x Friesian cows averaged significantly higher lactation yields than pure Sahiwals.

4.2.2.2 Lactation length. The mean lactation length for all the lactations recorded was 188 days. The effects of year of calving on lactation length were important ($P < .05$): there was a marked decline in average lactation length over the three years, with lactations averaging 70 days shorter in 1977 than in 1975. Month of calving had a significant effect on length of lactation: cows calving in January-February, March-April and September-October averaged 25 days longer lactations than cows calving in the other six months of the year. The effects of parturition number were also important ($P < .01$): lactations following the first and fourth parturitions were shorter than the overall average, while lactations following the four other parturitions were longer.

As expected, the milking system had a significant effect on lactation length. The average length of the 288 lactations recorded under the first milking system was 172 days longer ($P < .01$) than the average for the 113 lactations recorded under the second milking system.

Neither cow's breed of sire nor cow's sire within either breed had a significant effect on length of lactation. The only significant interaction was milking system with breed of sire, because cows by Sahiwal sires averaged shorter lactations than cows by Ayrshire sires under the first milking system and longer lactations under the second. Differences in lactation length between breeding groups of cows were not significant (Table 7).

4.2.2.3 Daily milk yield. Daily milk yield averaged 7.2 kg for the 401 lactations

recorded. Neither year nor month of birth of calf had an important effect on daily milk yield, but the effects of parturition number were significant ($P < .01$). Daily milk yield following first and second parturitions averaged 1.4 and 0.3 kg less, respectively, than the overall average. Cows under the first milking system produced on average 1.3 kg more ($P < .01$) milk per day than cows under the second milking system.

Cows by Ayrshire sires averaged 1.4 kg more milk ($P < .01$) per day than cows by Sahiwal sires, but differences between individual sires were not significant within either breed. None of the interactions involving year and milking system produced significant differences.

Differences between breeding groups of cows were significant, with purebred Sahiwal cows averaging significantly less milk per day than all other breeding groups (Table 7). This result was expected because the purebred Sahiwal cows which were milked also suckled their calves. The five other cow breeding groups did not differ significantly from each other in terms of daily milk yield ($P > .05$).

4.2.3 Growth Characters

4.2.3.1 Weaning weight. The mean weaning weight at 9 months for the 384 calves recorded in the survey was 163 kg. Although the effects of year of birth were not significant at the $P < .05$ level, average weaning weights declined over the 3-year period from 170 kg in 1975 to 164 kg in 1976 and 156 kg in 1977. Calves born in May-June and July-August were on average 15 kg lighter at weaning than calves born during the 8 other months of the year. Calves from first and second parturitions averaged 7 kg lighter ($P < .01$) at weaning than calves from third and fourth parturitions. Male calves averaged 11 kg heavier ($P < .01$) at weaning than females. The rearing system also had a significant effect on weaning weight (see section 4.1): calves reared under the first system, which were not allowed to suckle their own dams, averaged 146 kg at weaning. Those reared under the second system, which suckled their own dams but with a substantial proportion of the milk

taken for others, averaged 167 kg, and those reared under the third system, which had nearly all the milk from their own dams, averaged 176 kg. These results indicate that calves which are allowed to suckle their own dams have an advantage over those which are not.

Neither breed of sire nor breeding group of dam had a significant effect on weaning weight of calf (Table 8), but differences between the nine Ayrshire sires were significant. Differences between the eight Sahiwal sires were not significant; neither were any of the interactions involving breeding group of dam, breed of sire, year or rearing system.

Although the interaction of breed of sire with breeding group of dam was not significant for weaning weight, because of interest in specific crosses, breed of sire - breeding group of dam subclass means and their standard errors are presented in Table 9 for weaning weight and calf survival.

4.2.3.2 Steer weights adjusted to constant ages of 27, 30 and 36 months. Differences in the growth of the 141 steers kept after weaning were analyzed initially in terms of month of birth, breed of sire, breeding group of dam and the interaction of breed of sire with breeding group of dam. The effects of year of birth were then excluded from the model used for the final analysis because they had not been significant.

The evaluation of steer growth after weaning included 14 Sahiwal x Friesian steers, but purebred Sahiwal steers were not included. Neither breeding group of dam nor month of birth was significant ($P > .05$) for steer weights adjusted to 27, 30 and 36 months. However, the effects of breed of sire were significant: steers by Sahiwal sires averaged 64 kg heavier than steers by Ayrshire sires at 27 months, 65 kg heavier at 30 months and 76 kg heavier at 36 months (Table 8). The fact that major differences in growth rate were observed after weaning, while there was no significant difference at weaning (162 kg for Sahiwals vs 164 kg for Ayrshires) suggests that the nutritional environment provided before weaning may not have been adequate to allow expression of differences between the two breeds in terms of

Table 9. Least-squares breeding group means and standard errors for calf survival and weaning weight by breed of sire-breeding group of dam subclass, Cedervale Farms

Breeding group of calf[a]	Calf survival		Weaning weight	
	N	%	N	kg
Ayrshire x 3/4 S - 1/4 A	234	82 ± 2.8	112	160 ± 7.4
Ayrshire x 1/4 S - 3/4 A	13	91 ± 11.4	5	174 ± 18.5
Ayrshire x S - A	63	79 ± 5.2	24	159 ± 10.8
Ayrshire x S - crossbred Friesian	55	75 ± 5.9	24	166 ± 14.0
Sahiwal x Sahiwal	84	60 ± 6.1	31	159 ± 15.5
Sahiwal x 3/4 S - 1/4 A	58	77 ± 6.3	15	146 ± 13.3
Sahiwal x 1/4 S - 3/4 A	207	89 ± 4.3	126	169 ± 6.9
Sahiwal x S - A	56	92 ± 6.9	28	162 ± 11.3
Sahiwal x S - crossbred Friesian	29	96 ± 10.5	19	176 ± 13.7

[a] A = Ayrshire, S = Sahiwal; sire breed listed first.

additive genetic merit for growth.

4.2.4 Viability

4.2.4.1 Calf survival. Of the 799 calves born during the period under analysis, 79% survived until weaning at 9 months (Table 8). The effects of year of birth, month of birth, parturition number and sex were not significant for calf survival until weaning. Rearing systems did have a significant effect, however ($P < .01$): 69% of the calves reared under the first system survived until weaning, 84% of those reared under the second system survived, and 85% of those reared under the third system. The effects of breeding group of dam were significant for calf survival, but the effects of breed of sire were not (Table 8). Also the interaction of breeding group of dam by rearing system was significant: 90% of the calves out of 3/4 Sahiwal - 1/4 Ayrshire dams survived under the first rearing system.

Only 56% of the calves out of purebred Sahiwal cows survived until weaning, which was significantly different ($P < .01$) from the overall average. Several factors probably contributed to this low survival rate. For one thing, the purebred Sahiwal calves were the only straightbred calves produced - Sahiwal females were bred only to Sahiwal males - while Gregory et al (1978b) have shown that individual heterosis has an influence on calf survival. Also, the purebred Sahiwal calves may have had relatively high coefficients of inbreeding which has an effect opposite of heterosis on calf survival. Further, the owner suggested that the large teat size of some of the purebred Sahiwal cows may have made it difficult for their calves to suckle immediately after birth and thus they may have had a low nutrient intake and may not have received enough colostrum to provide adequate antibodies. Among Sahiwal calves that lived, the level of nutrition provided during the preweaning period was probably comparable to that of other breeding groups: their weaning weights averaged 160 kg compared to an average of 163 kg for all calves.

Deficiencies in udder and teat anatomy are a problem of the Sahiwal breed that may reduce its usefulness for both milk and beef production programmes.

However, Sahiwal crossbreds with breeds that have desirable udder and teat conformation seem to be generally acceptable in terms of these anatomical characteristics.

The interaction of breed of sire by breeding group of dam was significant for calf survival. This is due to the low survival rate of 56% for calves by Sahiwal sires out of Sahiwal dams, while the overall survival rate for all progeny of Sahiwal sires was 7% higher than for the progeny of Ayrshire sires across all breeding groups of cows (Table 8).

4.2.4.2 Cow mortality. Data on cow mortality from Cedarvale Farms are presented in Table 10. Obviously, the standard errors on percentage of cow mortality are large for the five breeding groups of cows. Thus it does not seem appropriate to attempt to draw inferences from the results observed for this character.

Table 10. Cow mortality, Cedarvale Farms

Breeding group of cow	Number of cow years	Number of deaths	Cow mortality
3/4 Ayrshire - 1/4 Sahiwal	148	2	1.4
Ayrshire x Sahiwal and reciprocal	64	3	4.7
3/4 Sahiwal - 1/4 Ayrshire	139	1	0.7
Purebred Sahiwal	25	0	0
Sahiwal x crossbred Friesian	25	5	20.0

4.2.5 Index of cow productivity

The characters of reproductive performance, cow and calf viability, milk production, growth and cow weight are combined in Table 11 to build up an index of

the total weight of 1-year-old calf plus the liveweight equivalent of milk produced, both per cow per year and per 100 kg of cow weight maintained per year. As already described, the cow productivity index is computed as the product of cow viability (%) x calving percentage (%) x calf survival (%) x calf weight at 1 year (kg) + cow viability (%) x calving percentage (%) x lactation milked-out yield (kg)/9.

Table 11. Productivity estimates of cows by breed group, Cedarvale Farms

Character	Sahiwal	3/4 Sahiwal-1/4 Ayrshire	Sahiwal-Ayrshire	1/4 Sahiwal-3/4 Ayrshire
Cow viability (%)	100	99.3	95.3	98.6
Calving percentage (%)	81.1	92.2	87.7	80.6
Calf survival (%)	55.5	75.8	81.8	85.8
Calf weight at 1 year (kg)	187.2	180.2	188.2	198.2
Lactation milked-out yield[a] (kg)	1050	1458	1635	1626
Productivity index per cow per year[b] (kg)	178.9	273.3	280.5	278.7
Cow weight (kg)	418	437	413	408
Productivity index per 100 kg of cow maintained per year[b] (kg)	42.8	62.5	67.9	68.3

[a] Adjusted to the proportions of animals actually maintained under each rearing and milking system.

[b] Total weight of 1-year-old calf plus liveweight equivalent of milk produced.

The lactation milked-out yield values included in the cow productivity index for Cedarvale Farms (Table 11) differ from the total lactation yield values presented in Table 7 because the values used in the cow productivity index were adjusted to reflect the proportion of animals actually maintained in each milking and rearing system. The productivity estimates of cows by breed group show little difference between the Sahiwal - Ayrshire and the 1/4 Sahiwal - 3/4 Ayrshire

breeding groups. It appears that milk production and other components of the index are reduced for cows which are more than one-half Sahiwal. The low rate of calf survival is a major factor, in addition to low milk production, contributing to the low indices of the purebred Sahiwal cows.

4.2.6 Heterosis and reciprocal effects

4.2.6.1 Reciprocal cross differences. Among Ayrshire-Sahiwal reciprocal cross females, those with Sahiwal dams averaged 43 days ($P > .05$) earlier at first calving (Table 12). Cows with Ayrshire dams averaged a 59-day shorter calving interval, or 386 days compared with 445 ($P < .01$), but cows with Sahiwal dams averaged 34-day longer lactations and 0.6 kg greater daily milk yields ($P > .05$). It seems likely that the shorter calving interval of the Sahiwal x Ayrshire cows is related to their shorter lactations and lower daily milk yields. In the same nutritive environment, calving interval is generally increased as milk production increases.

4.2.6.2 Heterosis. A comparison of the average values for maternal characters of the reciprocal Sahiwal and Ayrshire backcrosses with the F_1 reciprocal crosses provides an estimate of heterosis (Table 12). Such a comparison should indicate that the reciprocal backcrosses and the F_1 reciprocal crosses achieve the same level of additive genetic merit, while the reciprocal backcrosses have lost one-half of the level of heterozygosity of the F_1 reciprocal crosses. In a comprehensive review article, Gregory and Cundiff (1980) concluded that the loss of heterosis in rotation crossbreeding systems is proportional to the loss of heterozygosity for both individual and maternal characters in cattle. Thus, heterosis is expected to be equal to the difference between the mean for the F_1 reciprocal crosses and the mean for the reciprocal backcrosses, multiplied by a factor of 2 because of expected loss of heterozygosity in the backcrosses.

Estimates of heterosis computed on this basis are presented in Table 12. The reciprocal backcross cows calved at a younger age than the F_1 crosses, however,

Table 12. Difference between reciprocal crosses and heterosis for maternal characters, Cedarvale Farms

Breeding group of cow	Age at first calving		Calving interval		Lactation			
	N	days	N	days	N	Total yield kg	Length days	Daily yield kg
Mean of Ayrshire x Sahiwal and reciprocal crosses	68	1084	227	416	64	1684	203	7.5
Mean of 3/4 Ayrshire - 1/4 Sahiwal and 3/4 Sahiwal - 1/4 Ayrshire	298	1068	334	424	287	1569	194	7.3
Difference between reciprocal crosses and reciprocal backcrosses		16		-8		115	9	0.2
Heterosis (difference x 2)				-16		230	18	0.4
Difference between reciprocal crosses[a] Ayrshire-Sahiwal - Sahiwal-Ayrshire		-43		59[a]		535	34	0.6

[a] $P < .01$.

so there is no basis for presenting an estimate of heterosis for this character. Based on differences between the reciprocal crosses and the reciprocal backcrosses, heterosis effects resulted in a reduced calving interval of 16 days, an increased lactation yield of 230 kg, an increased lactation length of 18 days, and an increased daily milk yield of 0.4 kg.

4.2.7 General remarks

The differences in milking and rearing systems carried out at Cedarvale Farms make it difficult to interpret the results of this study of production characters. However, the influence of different management systems and other environmentally related variables was estimated in the analysis, and adjustments in the breeding group means were made accordingly. There were significant differences among the six breeding groups of cows in age at first calving, calving interval and total and daily lactation yields (Table 7), as well as differences between sire breeds in postweaning growth rate of their steer progeny (Table 8).

The evidence presented shows that Sahiwals probably reach reproductive maturity at a later age than Ayrshires, based on age at first calving, that Sahiwal-sired cows tend to have shorter calving intervals than Ayrshire-sired cows, and that the Ayrshire breed has superior additive genetic merit for characters relating to lactation performance. The Sahiwal breed most likely excels the Ayrshire breed in additive genetic merit for growth when the nutritive environment is adequate to allow differences in additive genetic merit to be expressed.

A primary role of the Sahiwal breed may be to contribute germ-plasm, either through organized crossbreeding systems and/or through the formation of composite breeds, to obtain the benefits of heterosis and to achieve a more favourable production response capability in different climatic and nutritional environments. A more comprehensive discussion of the potential for forming composite breeds is presented in Chapter 8.

The low rate of survival of the purebred Sahiwal calves in this situation suggests that purebred Sahiwals may be lacking in vigour at birth. However, the transmitted effects for survival revealed by breed-of-sire means for calf survival indicate that the Sahiwal breed is a least equal to, and possibly slightly superior, to the Ayrshire breed in this character (Table 8). The general environment under which this herd is maintained would be classified as fairly harsh for dairy programmes, and breeding systems to utilize heterosis with some germ-plasm contributed by *Bos indicus* cattle seem essential for achieving an acceptable response level under these conditions.

Even though the data are not the most appropriate for providing estimates of heterosis for maternal characters, indications are that heterosis is of importance for most characters that contribute to maternal performance. There was a significant difference between the Ayrshire-Sahiwal cross and its reciprocal in calving interval, though a biological basis for this reciprocal effect is not apparent.

14. 10-year-old Sahiwal cow, Cedarvale Farms

15. 3/4 Sahiwal - 1/4 Ayrshire cow herd, Cedarvale Farms

16. 1/4 Sahiwal - 3/4 Ayrshire and 3/4 Sahiwal - 1/4 Ayrshire calves at 8 months, Cedarvale Farms

5. EL KARAMA RANCH

5.1 BACKGROUND INFORMATION

El Karama Ranch is located on the equator in Kenya's Rift Valley Province near Nanyuki. The ranch comprises about 4800 ha at an elevation of approximately 1800 m. Annual rainfall averaged 691 mm from 1972 through 1978, but a severe drought occurred in the area during this period, beginning in late 1974 and continuing through early 1976. Ordinarily, rainfall occurs in a bimodal pattern, with the main rainy season from April through June and a shorter rainy period from October through November.

The data analyzed were collected from populations of pedigree Boran and pedigree Sahiwal cattle. The ranch is managed primarily to produce bulls of both breeds to sell for breeding purposes in predominantly beef production programmes, both domestically and for export. Both herds were established in 1963. The Boran herd was started with foundation females that were typically Boran but lacked ancestoral records. Foundation sires for the Boran herd were obtained from pedigree breeders in the Kenya highlands. Boran bulls used subsequently have come from the same or similar sources or from the ranch's own herd. The Sahiwal herd was graded up by the use of pedigreed Sahiwal sires on an initial

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female population of Boran crosses with Red Poll and Hereford. Sahiwal sires have been obtained from the National Sahiwal Stud at Naivasha and from other Sahiwal breeders in Kenya and in recent years some Sahiwal sires have been produced on the ranch. The sample of sires used for both breeds is believed to be a representative sample of these breeds in Kenya.

Generally, feeding is restricted to natural grazing and no supplements are given. Herds of both breeds are grazed on the open range during the day under the care of a herdsman and are confined at night with no grazing. The predominant grasses are *Themeda* and *Brachiaria* species, with acacia trees scattered over the grasslands at varying densities. In addition to the cattle herds, the rangelands support large populations of zebra, giraffe, many species of antelope and some cape buffalo. The ranch owner estimates the carrying capacity at about 4.8 ha per livestock unit. The cattle must walk up to 7 km to water during much of the year and a similar distance to be dipped twice a week.

All breeding has been by natural service and the cows are exposed to bulls continuously. Thus, calves are born in all months of the year. Calves are weaned at 8 months and male calves are castrated after weaning. After weaning, heifer calves of both breeds are grazed together until they reach about 275 kg at an average age of 660 days, at which time they are exposed for breeding. Bull calves of both breeds are run together with steers and with older bulls after they are weaned. The management programme is the same for both breeds except some Sahiwal cows are milked once a day, primarily for domestic consumption. Milk is extracted in the morning when the calf is brought back to its dam after being separated overnight.

A subjective system of evaluating Sahiwal cows for milk production was used. On the basis of this system, 40% were classified as 'good' milkers, 32% as 'average' milkers and 21% as 'poor' milkers; a further 7% produced no milk beyond that consumed by the calf. Thus, some milk was extracted from 93% of the Sahiwal cows.

All traits were analyzed by least-squares fixed-model procedures (Harvey, 1972). The model for all traits included the fixed effects of year of birth, month of

birth, breed, and sire within breed. In addition, for the characters of calving interval and weaning weight, the model included parturition number and the interaction of breed with year. Sex of calf was included in the model for weaning weight. The residual mean square was used as the error term to test the significance of all differences evaluated.

5.2 RESULTS AND DISCUSSION

5.2.1 Reproductive characters

5.2.1.1 Age at first calving. The mean age at first calving was 1209 days for the 329 reproducing females included in the study. The effects of cow's year of birth were important ($P < .01$), with a general trend towards a lower age at first calving over the period of the study from 1964 through 1974. The one exception was cows born in 1973, as they were first exposed to breeding during the severe drought from late 1974 until 1976. Cows born in all years after 1969, except 1973, calved on average at an earlier age than the overall average, while cows born from 1964 through 1968 tended to calve at an older than average age. By contrast, month of cow's birth did not have a significant effect on age at first calving.

Breed differences in age at first calving were not significant (Table 13). Differences among cows sired by the 10 Sahiwal sires used were significant, while differences among cows sired by the 10 Boran sires were not. Thus, a large amount of additive genetic variation is indicated in the Sahiwal breed for this character.

5.2.1.2 Calving interval. The mean calving interval was 402 days for 990 observations from 1968 through 1977. The calf's year of birth had a significant effect on calving interval: cows calving in 1969, 1971, 1972, 1976 and 1977 averaged shorter calving intervals than the sample as a whole, while cows calving in 1970, 1973, 1974 and 1975 tended to have longer than average calving intervals. The longer

Table 13. Least-squares breeding group means and standard errors for maternal and growth characters, El Karama Ranch

	Age at first calving		Calving interval		Calf survival		Weaning weight		Adjusted 660-day weight of heifers		Adjusted 18-month weight of bulls		Adjusted 24-month weight of bulls		Adjusted 30-month weight of bulls	
	N	days	N	days	N	%	N	kg	N	kg	N	kg	N	kg	N	kg
Boran	157	$1223^{a} \pm 13.6$	498	$413^{a} \pm 8.1$	585	94^{a}	292	$170^{a} \pm 2.6$	105	$292^{a} \pm 4.7$	53	308	32	388	17	446
Sahiwal	172	$1195^{a} \pm 15.3$	492	$390^{b} \pm 8.6$	634	96^{a}	414	$170^{a} \pm 2.6$	122	$266^{b} \pm 4.4$	37	307	27	403	15	430

[ab] Means having no superscript letter in common differ at the $P \leq .05$ level.

calving intervals for cows calving in 1973, 1974 and 1975 are probably related to severe drought conditions which would have lowered the nutritive environment from late 1974 until 1976. The calf's month of birth did not significantly affect calving interval.

Parturition number had an important effect on calving interval ($P < .01$). The calving interval between first and second parturitions averaged 441 days, while the interval before the seventh (last) parturition averaged 429 days. For all other parturitions, the calving interval was shorter than the overall mean of 402 days. For the younger cows, the longer than average calving interval probably reflected higher nutritive requirements, because they still had a nutritive requirement for growth in addition to nutritive requirements for lactation and maintenance. The longer calving interval for the older cows is probably due to a reduced ability to cope with nutritional and other stress factors associated with the aging process.

The effects of breed on calving interval were significant: the calving interval for Sahiwal cows was 23 days shorter on average than for Boran cows (Table 13). As already mentioned, some milk was extracted from most of the Sahiwal females though the Sahiwal and Boran herds were kept under a similar nutritive environment. Thus, it appears that Sahiwal cows can return to estrus more quickly following calving than Boran cows, even though they produce more milk in a similar nutritive environment.

Differences in calving interval were not significant among cows by 19 Boran sires or those by 9 Sahiwal sires. The interaction of breed with year of birth of calf was significant for calving interval, however. This result is not readily interpretable: the Boran cows averaged a 35-day shorter calving interval in 1976, while the Sahiwal cows averaged a 36-day shorter calving interval in 1975, both of which were drought years. This reversal between the two breeds in the two years accounts for the significant interaction, but the pattern is not interpretable based on the effects of drought. The ranch owner suggested that the Boran may have been better able to cope with adverse conditions than the Sahiwal, but the data on calving interval do not confirm this view.

5.2.2 Growth characters

5.2.2.1 Weaning weight. The mean weaning weight at 8 months was 170 kg for the 706 calves on which records were analyzed. Year of birth had a significant effect on weaning weight: the average weaning weights for calves born in 1972, 1973 and 1974 were below the overall average, while weaning weights for calves born in 1975, 1976 and 1977 were higher on average than for the sample as a whole. This pattern is not consistent with what would be expected during the drought period. Month of birth also had an important effect on weaning weight ($P < .01$): calves born from July through December averaged 7 kg lighter at weaning than the overall average, while calves born from January through June averaged 7 kg heavier at weaning than the group as a whole. Calves born from January through April averaged 9 kg heavier at weaning than the overall average.

Parturition number did not have a significant effect on weaning weight. This is an interesting result in view of the fact that calving intervals were longer on average for the first and the last parturitions. These results indicate that lactation yields are maintained, even at the expense of subsequent reproductive performance. Thus, during periods of inadequate nutrition, reduced reproductive performance, as reflected by increased calving interval, would be expected before a decline in weaning weight.

The influence of sex of calf was important for weaning weight ($P < .01$): male calves averaged 18 kg heavier at weaning than females. This difference is consistent with reports in the literature (Smith et al, 1976b; Gregory et al, 1978b, 1978c and 1979b). Differences among the 10 Boran sires were not significant for the weaning weight of calves, but differences among the 15 Sahiwal sires were significant.

The interaction of breed with year was important ($P < .01$) for weaning weight: Boran calves averaged 19 kg heavier at weaning than Sahiwal calves in 1975 and slightly heavier in 1976 and 1977, while Sahiwal calves averaged 13 kg heavier than

Boran calves in 1972 and 1973. Overall, however, the two breeds did not differ in terms of weaning weight: they both averaged 170 kg (Table 13).

5.2.2.2 Adjusted weight of heifers at 660 days. The average age at which heifers entered the breeding herd was 660 days. At this age, their average weight was 279 kg. Heifers were not removed from either breed group for any reason, other than death, prior to this age. Thus, no bias has been introduced as a result of sequential culling or selection, and the 660-day weight of heifers is the most appropriate indicator of differences between the Boran and Sahiwal breeds in terms of additive genetic merit for growth.

Year of birth had a significant effect on the weight of heifers at 660 days: Heifers born in 1972 and 1973 averaged 26 kg lighter and heifers born in 1974 averaged 6 kg lighter than the group as a whole, while heifers born in 1975 and 1976 averaged 29 kg heavier. These results do not seem to be associated with the 1974-1976 drought period. The effects of month of birth were also important ($P < .01$): in contrast to the effect of month of birth on weaning weight, heifers born during the first six months of the year were 13 kg lighter on average at 660 days than the group as a whole, while heifers born from July through December averaged 13 kg heavier. Heifers born in March and April averaged 26 kg lighter at 660 days than the overall average, and heifers born in September and October averaged 25 kg heavier. Thus, the seasonal effect associated with month of birth which influences weaning weight in one direction influences the 660-day weight of heifers in the opposite direction. This observation reflects the importance of seasonal effects on postweaning growth.

Boran heifers were 26 kg heavier ($P < .01$) on average in terms of adjusted 660-day weight than Sahiwal heifers (Table 13), while there was no difference between the two breeds in weaning weight at 8 months. This implies that the Sahiwal cows were superior to the Boran cows in maternal ability as reflected in weaning weight even though some milk was extracted from most of the Sahiwals. This superiority was apparently sufficient to offset the superiority of the Boran in

additive genetic merit for growth as reflected in greater postweaning gains.

5.2.2.3 Adjusted weight of bulls at 18, 24 and 30 months. Some bull calves were culled at weaning according to weaning weight, pedigree, colour and muscular and skeletal anatomy. Also, some bulls were culled on a continuing basis between weaning and 30 months based on performance characters as well as other criteria which could affect their marketability as breeding animals. Thus, the adjusted weight records for bulls (Table 13) are subject to differential selection bias for the two breeds and should be interpreted accordingly.

5.2.3 Viability

5.2.3.1 Calf survival. Of all the calves born, 95% survived until weaning at 8 months (Table 13). Though year of birth did not have a significant effect on calf survival, a trend was discernible towards an increasing rate of survival over the period for which data were collected. The effects of month of birth on calf survival were also not significant. Though the effects of parturition number were not significant, there was a tendency towards greater calf survival in later parturitions. The effects of sex of calf were not significant for survival to weaning, but survival was 2% greater for Sahiwal calves than for Boran ($P < .05$).

5.2.3.2 Cow mortality. From 1968 through 1977, 1% of the Boran cows died and 2% of the Sahiwals. This is considered an unusually low level of cow mortality for both breeds.

5.2.4 Index of cow productivity

The characters of reproductive performance, cow and calf viability, milk production, growth and cow body weights are combined in Table 14 to build up an index of the total weight of 1-year-old calf plus the liveweight equivalent of milk produced, both per cow per year and per 100 kg of cow weight maintained per year.

As for the other production situations, the cow productivity index is computed as the product of cow viability (%) x calving percentage (%) x calf survival (%) x calf weight at 1 year (kg) + cow viability (%) x calving percentage (%) x lactation milked-out yield (kg)/9.

Table 14. Productivity estimates of cows by breed group, El Karama Ranch

Character	Sahiwal	Boran
Cow viability (%)	97.7	99.1
Calving percentage (%)	93.6	88.4
Calf survival (%)	96.0	94.0
Calf weight at 1 year (kg)	205.6	211.9
Lactation milked-out yield (kg)	90	-
Productivity index per cow per year[a] (kg)	190.5	174.5
Cow weight (kg)	418	414
Productivity index per 100 kg of cow maintained per year[a] (kg)	45.6	42.2

[a] Total weight of 1-year-old calf plus liveweight equivalent of milk produced.

The Sahiwal cows exceeded the Boran by 9.2% in terms of the productivity index per cow per year and by 8.0% in terms of the productivity index per 100 kg of cow maintained per year. These figures take account of the milk which was extracted from the Sahiwal cows.

5.2.5 General remarks

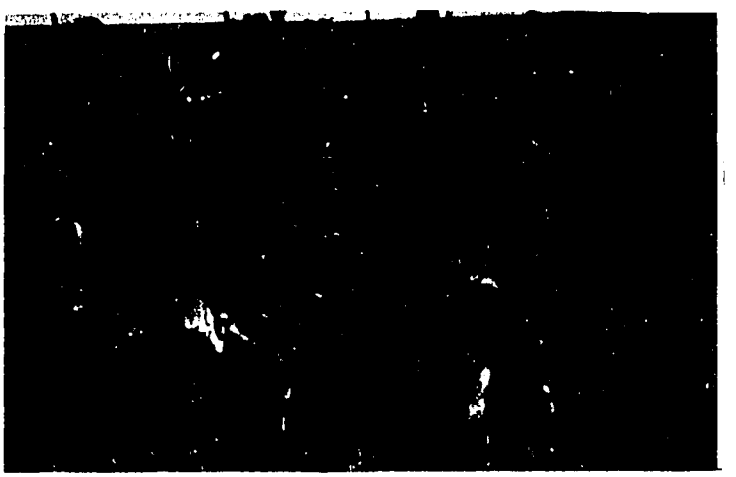
This study provides comparative information on relevant beef production characteristics of the Sahiwal and Boran breeds as purebreds under the extensive conditions typical of many higher-potential sites in Africa's arid to semi-arid

ecological zones. This comparative information provides a basis for making informed decisions on the use of these breeds in organized crossbreeding systems or as contributors to composite breeds to achieve a more favourable additive genetic composition for beef production in such environments. Both approaches would involve the use of heterosis. The Boran has been the *Bos indicus* breed used most widely as a standard of comparison for beef production programmes in many of the high-elevation arid to semi-arid areas of eastern Africa. These results show that the Sahiwal breed is also adapted to beef production programmes and may be used to complement the Boran, either in crossbreeding systems or as a contributor to composite breeds.

The advantage of Sahiwals shown in this analysis in terms of calving interval, combined with equal calf and cow survival rates and weaning weights, indicates the adaptability of this breed to more extensive beef production environments in terms of fitness-related characters. The shorter calving interval and equal weaning weight were achieved by Sahiwal cows even though some milk was extracted. Thus, it appears that the Sahiwal breed has higher additive genetic merit than the Boran for calving interval and maternal ability under the extensive beef production systems represented in this analysis, while the Boran has greater additive genetic merit for growth, as shown by the greater weight of Boran heifers at 660 days. The Sahiwals appear to compensate for inferior additive genetic merit for growth by superior merit for maternal ability, resulting in equal calf weights at weaning. The index of cow productivity which takes account of the estimated milk extracted from the Sahiwal cows, shows an advantage of the Sahiwal over the Boran breed in estimated net merit, based on the estimated weight equivalent of 1-year-old calf produced.

Given the heavier weight of Boran heifers at 660 days, mature Boran cows would be expected to be heavier than Sahiwals. However, cows of the two breeds did not differ significantly ($P > .05$) in terms of mature weight (Table 14). As only 32 cows of each breed were weighed, this discrepancy may be explained by sampling error, particularly as the ranch owner expressed the view that his Boran cows were normally fatter than the Sahiwals. It is likely that Boran cows tend to be heavier at maturity than Sahiwals, in spite of the results from this sample.

17. Sahiwal cow and calf herd, El Karama Ranch



18. Sahiwal cow, El Karama Ranch

19. Boran cow and calf herd, El Karama Ranch

6. ILKERIN PROJECT

6.1 BACKGROUND INFORMATION

Data were analyzed from Sahiwal and East African Zebu herds maintained by the Roman Catholic Church as part of the Ilkerin Development Scheme. The project staff manage the Ilkerin farm in the Loita Hills of southwestern Kenya near Morijo. The ranch lies at a latitude of 1.7° S and an elevation of approximately 2200 m. Annual rainfall from 1974 through 1978, when data were collected, averaged 610 mm, falling in a bimodal pattern with the main rainy season from April through June and a rainy period from October through November.

This study involved the analysis of lactation records on 29 East African Zebu and 102 Sahiwal cows collected from 1974 through 1976. Also, lactation data were collected in 1978 on 37 East African Zebu and 53 Sahiwal cows. From 1974 through 1976, cows were milked once a day in the morning after being separated from their calves overnight and were suckled once later in the day. After the first two and one-half months of lactation, the cows were milked twice a day. For the lactation records obtained in 1978, calves were separated from their dams and the cows were fully milked out twice a day with calves allowed to suckle the limited amounts available afterwards.

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Birth weights were recorded on 53 Sahiwal x East African Zebu cross calves and on 106 straightbred Sahiwal calves, and weaning weights were recorded on 48 Sahiwal x East African Zebu cross calves and 75 straightbred Sahiwal calves, born from 1974 through 1978. Weaning weights were adjusted to 240 days.

All characters were analyzed by least-squares fixed-model procedures (Harvey, 1972). As appropriate for each character involved, the model was varied in regard to the factors included. The specific factors included in the model for the analysis of each character will be evident when results are presented and discussed for the specific characters.

6.2 RESULTS AND DISCUSSION

6.2.1 Reproductive characters

6.2.1.1 Age at first calving. The dates of birth of the East African Zebu cows included in the study were not known, so it was not possible to analyze differences between the East African Zebus and the Sahiwals in terms of age at first calving. The age at first calving for 40 of the Sahiwal cows included in the study, whose birth dates were known, averaged 1147 days.

6.2.1.2 Calving interval. Calving intervals recorded from 1974 through 1976 averaged 473 days. Calving interval was significantly influenced by year of calving, averaging 358 days in 1974, 456 days in 1975 and 604 days in 1976. The month of calving did not influence calving interval significantly, however ($P > .05$). Parturition number was a significant influence: calving intervals averaged 546 days after the first parturition, 462 days after the second and 411 days after the third parturition. The two breeds did not differ significantly in terms of calving interval, nor was the interaction of breed with year significant. However, the straightbred Sahiwal cows averaged a 38-day shorter calving interval than the East African Zebus (Table 15).

Table 15. Least-squares breeding group means and standard errors for maternal characters, Ilkerin Project

	1974 - 76[a]						1978[b]			
		Lactation yield	Lactation length	Daily milk yield	Calving interval			Lactation yield	Lactation length	Daily milk yield
	N	kg	days	kg	N	days	N	kg	days	kg
East African Zebu	29	34[c] ± 95	111[c] ± 31	0.7[c] ± 0.2	22	492[c] ± 47	37	244[c] ± 57	176[c] ± 21	1.4[c] ± 0.2
Sahiwal	102	595[d] ± 56	222[d] ± 18	2.5[d] ± 0.1	102	454[c] ± 28	53	420[d] ± 37	146[c] ± 14	2.7[d] ± 0.2

[a] Cows milked once a day and suckled once a day for the first 2.5 months, then milked twice a day with limited suckling by calf.

[b] Cows fully milked out with limited suckling by calf.

[cd] Means with no superscript letter in common differ at the $P \leq .05$ level.

6.2.2 Milk production

6.2.2.1 Lactation yield. Lactation yields were not significantly influenced by year of calving among the cows analyzed for the period 1974 through 1976, but the effect of month of calving was significant ($P < .05$). Cows calving from January through April produced an average of 142 kg more milk per lactation than the overall average. Neither parturition number nor the interaction of breed with year were important ($P > .05$) for lactation yield, but the effects of breed on lactation yield were significant: when suckled by their calves and milked once a day, the East African Zebu cows produced an average of 34 kg of milk per lactation, while the Sahiwal cows averaged 595 kg ($P < .01$).

Among the cows analyzed for 1978, month of calving did not significantly influence lactation yield, but parturition number had a significant effect. The effect of parturition number on lactation yield was not consistent, however: lactation yield was highest, at 522 kg on average, following the third parturition and lowest, averaging 204 kg, following the fourth. Lactation yields averaged 244 kg for the 37 East African Zebu cows and 420 kg for the 53 Sahiwals ($P < .01$), with both breeds fully milked out twice a day (Table 15).

6.2.2.2 Lactation length. The average length of lactations recorded in 1974, 1975 and 1976 was 166 days. Neither the effects of year or month of birth, parturition number nor the interaction of breed with year was significant for lactation length. The mean lactation length was 111 days for the East African Zebu cows and 222 days for the Sahiwals ($P < .01$) (Table 15). For cows that were fully milked out in 1978, neither month of birth of calf, parturition number nor breed significantly influenced lactation length.

6.2.2.3 Daily milk yield. For the data collected from 1974, 1975 and 1976, neither year of birth, parturition number nor the interaction of breed with year was significant for daily milk yield. The effects of month of calving were important ($P < .05$): cows calving during January-February and March-April averaged 0.4 kg more milk a day than the overall average. The East African Zebu cows

averaged 0.7 kg milk per day and the Sahiwals 2.5 kg ($P < .01$).

Month of birth did not significantly influence daily milk yield for the cows recorded in 1978. Parturition number did influence ($P < .01$) daily milk yields for this sample, however: daily production following the first and fourth parturitions averaged 0.3 kg less than the overall average. The East African Zebu cows averaged 1.4 kg milk per day, while the Sahiwals averaged 2.7 kg ($P < .01$) (Table 15).

6.2.3 Growth characters

6.2.3.1 Birth weight. Birth weight records were analyzed for 53 Sahiwal x East African Zebu calves and 106 Sahiwal calves born from 1975 through 1978. The effects of year of birth were significant: calves born in 1976 and 1977 averaged 3.2 kg lighter at birth than calves born in 1975 and 1978. Month of birth was also significant ($P < .01$): calves born from September through December averaged 1.9 kg lighter at birth than the average for all calves of 19.8 kg. Parturition number did not have a major influence on birth weight, however ($P > .05$). The influence of sex was significant: male calves weighed on average 2.2 kg more at birth than female calves, or 20.9 vs 18.7 kg. Straightbred Sahiwal calves were significantly heavier at birth than Sahiwal x East African Zebu cross calves (Table 16).

6.2.3.2 Weaning weight. Weaning weight records were analyzed on 48 Sahiwal x East African Zebu calves and 75 straightbred Sahiwal calves born from 1974 through 1978 during the months of March through September. The average weight at weaning for the entire sample was 100 kg. Year of birth had an important effect on weaning weight ($P < .01$): calves born in 1978 averaged 14 kg heavier at weaning than the overall average for all calves. Neither month of birth nor parturition number significantly influenced weaning weight, but the effects of sex of calf on weaning weight were important ($P < .01$): male calves averaged 10 kg more at weaning than female calves. The difference between breeding groups was also sig-

nificant: straightbred Sahiwal calves averaged 16 kg more at weaning than Sahiwal x East African Zebu calves (Table 16).

Table 16. Least-squares breeding group means and standard errors for growth characters, Ilkerin Project

	Birth weight		Weaning weight		Calf survival	
	N	kg	N	kg	N	%
Sahiwal x East African Zebu	53	19.2[a] ± 0.73	48	92[a] ± 3.8	83	95[a]
Sahiwal	106	20.5[b] ± 0.49	75	108[b] ± 3.0	187	96[a]

[ab] Means with no superscript letter in common differ at the $P \leq .05$ level.

6.2.4 Viability

6.2.4.1 Calf survival. Similar proportions of Sahiwal calves and Sahiwal x East African Zebu calves survived to 12 months. Calf survival to approximately 12 months was 96% for the Sahiwals and 95% for the East African Zebus (Table 16).

6.2.4.2 Cow mortality. Mortality was greater among Sahiwal than among East African Zebu cows. A total of 14 Sahiwal cows died out of the 242 cow-years analyzed, giving an annual mortality rate of 6%. Only 3 East African Zebu cows died out of 108 cows-years, giving a 2.8% annual mortality rate. Standard errors are large for these values, however, so the difference between breed groups is not significant.

6.2.5 Index of cow productivity

The characters of reproductive performance, cow and calf viability, milk production, growth and cow weight are combined in Table 17 to build up an index of the total weight of 1-year-old calf plus the liveweight equivalent of milk produced, both per cow per year and finally per 100 kg of cow maintained per year. As in the other production situations, the cow productivity index is computed as the product of cow viability (%) x calving percentage (%) x calf viability (%) x calf weight at one year (kg) + cow viability (%) x calving percentage (%) x lactation milked-out yield (kg)/9.

The cow weights provided in Table 17 are estimates based on data from other sources, as the actual cows for which productivity data were obtained were not weighed. According to this index, the Sahiwal cows were 77% more productive than the East African Zebus per cow per year. However, when the productivity index is expressed on the basis of estimated weight of cow maintained per year, the difference in favour of the Sahiwal cow is reduced to 24% (Table 17).

Table 17. Productivity estimates of cows by breed group, Ilkerin Project

Character	East African Zebu	Sahiwal
Cow viability (%)	97.2	94.2
Calving percentage (%)	74.2	80.4
Calf survival (%)	95.2	95.7
Calf weight at 1 year (kg)	128.0	152.0
Lactation milked-out yield (kg)	34	595
Productivity index per cow per year[a] (kg)	90.6	160.3
Cow weight (kg) (estimated)	(280)	(400)
Productivity index per 100 kg of cow maintained per year[a] (kg) (estimated)	(32.4)	(40.1)

[a] Total weight of 1-year-old calf plus liveweight equivalent of milk produced.

6.2.6 General remarks

The results from this study comparing lactation characteristics show the Sahiwal breed to be greatly superior to the East African Zebu breed for characters that contribute to milk production. Also, straightbred Sahiwal calves are significantly heavier at birth and at weaning than Sahiwal x East African Zebu cross calves, even though the crosses have the benefit of heterosis for growth rate. Survival rates are similar for straightbred Sahiwal and East African Zebu cross calves. Thus, the Sahiwal breed is superior to the East African Zebu breed in transmitted effects for lactation and growth-related characters. The 38-day advantage in calving interval in favour of the straightbred cows indicates that they are at least equally well adapted to the environment.

The conditions under which these comparisons were made at the site of the Ilkerin Project are classified as harsh in regard to nutritional environment. It is concluded that the Sahiwal breed has potential for use in both milk and beef production programmes under adverse environmental conditions as found at this site. The potential of the Sahiwal breed under such conditions would appear to be greatest in organized crossbreeding programmes or as a contributor to composite breeds, rather than as a straightbred.

7. BREED AND ENVIRONMENTAL EFFECTS ON PRODUCTIVITY LEVELS

7.1 SUMMARY OF THE PRODUCTION POTENTIAL OF THE FIVE SITES

In the broadest sense, the five sites covered in this study can be considered as five different production environments, including factors of climate, soil fertility, management, nutritional supplementation and intensity and type of output demanded. These production factors have been described in the chapters on the individual sites. Using all objective measures available, plus the subjective knowledge contributed by the owners and managers of these ranches, the current production potential of each site has been evaluated under the specific management regimen currently in practice.

Over a period of time, all five ranches have introduced Sahiwal cattle, and various combinations of the Sahiwal breed with exotic *Bos taurus* and local *Bos indicus* breeds have been examined. In some cases the productivity of pure *Bos taurus* cattle has also been compared. It can be argued that each ranch has moved towards the broad genetic types most suited to its particular environmental situation and production system, and the best estimate of the current production potentials of the sites would appear to be the productivity index of the breeding groups most suited to each. The calculation of these indices has already been described: the

characters of reproductive performance, cow and calf viability, milk production, growth and cow body weight are combined to provide the total weight of 1-year-old calf plus the liveweight equivalent of milk produced, both per cow per year and per 100 kg of cow maintained per year.

Table 18 indicates the present production potential of each of the five sites, ranging from 64% to 145% of the overall average. These production potentials provide a broad ranking of the situations within which the influence of both genetic and environmental factors can be examined.

Table 18. Summary site descriptions

	Ilkerin	El Karama	Cedarvale	Deloraine	Kilifi
Annual rainfall (mm)	610	691	682	1007	1043
Elevation (m)	2200	1800	2000	2100	10
Annual potential evaporation (mm) (Woodhead, 1968)	1700	1900	1700	1900	2300
Pastures	natural	natural	seeded/ natural	seeded/ natural	natural
Estimated stocking rates	medium	medium	high	medium	high
Major products	milk/ meat	meat	milk/ meat	milk/ meat	milk
Supplementation	low	nil	low	medium	high
Breed type with greatest output at present	Sahiwal	Sahiwal	Sahiwal/ Ayrshire combi-nations	Sahiwal/ Ayrshire combi-nations	Sahiwal/ Ayrshire combi-nations
Productivity index/cow for most productive breed type	160	190	278	267	364
Productivity index relative to average for 5 sites (%)	64	75	110	106	144

7.2 PRODUCTIVITY OF DIFFERENT BREEDS AND CROSSES

Ilkerin has the lowest rainfall and a low and highly variable nutritive status. The data show that the Sahiwal breed is adapted to these conditions and is markedly superior to the Small East African Zebu in both milk production and growth rate. The 38-day shorter calving interval demonstrates the fitness of the Sahiwal breed in this environment.

El Karama has relatively low rainfall and desiccating winds which reduce the moisture available for plant growth. The area is also subject to droughts, a major reason for the emphasis on beef production. The results from this situation provide excellent comparative data on the Sahiwal and Boran breeds as straight-breds in a beef production environment.

The Sahiwal breed at El Karama proved superior to the Boran in maternal ability, whereas the Boran was probably superior in genetic merit for growth. Boran heifers were 10% heavier than Sahiwal heifers at 21 months but cows of the two breeds did not differ in mature weight. When account was taken of the milk that was extracted from the Sahiwal cows, they proved to be 9% superior to the Boran in terms of a productivity index per cow per year. The Boran breed has long been used as a standard of comparison in beef production programmes in eastern African locations with environmental conditions similar to El Karama: these results demonstrate that the Sahiwal is also well adapted to a beef production environment.

The three higher-potential sites, Cedarvale, Deloraine and Kilifi, all maintained pure Ayrshires, an exotic *Bos taurus* breed, at some stage, but only Deloraine Estates still maintains purebred Ayrshires today. Even though this site has a climatic environment to which pure exotic breeds of *Bos taurus* cattle are considered adapted, lying in the temperate highlands with 1000 mm mean annual rainfall, the nutritional levels available favour crosses of Ayrshire with Sahiwal. The Ayrshire-Sahiwal cross cows exceeded the pure Ayrshire cows by 4% in pro-

ductivity index per cow per year in spite of the fact that the Ayrshires received preferential feeding. The milked-out lactation yield was 185 kg greater for the straightbred Ayrshire cows than for the Ayrshire-Sahiwal crosses: it was the higher calving percentage and greater calf survival rate of the Ayrshire-Sahiwal cross cows that accounted for their higher productivity index.

Cedarvale has relatively low rainfall, but some improved pastures have been provided and management factors are manipulated substantially in response to environmental conditions. On the basis of cow productivity indices, the three crosses of Ayrshire and Sahiwal showed an average superiority of approximately 50% over pure Sahiwals. The optimum contribution by the Sahiwal breed to a population also based on the Ayrshire breed is between one-fourth and one-half in this type of environment. The indications are that milk production will be reduced when the contribution by the Sahiwal breed exceeds one-half.

At Kilifi, 2/3 Ayrshire - 1/3 Sahiwal cows outyielded 1/3 Ayrshire 2/3 Sahiwal cows by 7% for full lactations and 4% on an annual yield basis. In terms of the productivity index, their advantage was 3%. The level of nutrition provided at this site was the best of the five situations studied and most probably approached the level necessary for maximum expression of genetic differences between breeding groups. However, the climate, with high temperatures and high relative humidity, was the harshest of the five sites. In conclusion, the optimum contribution by the Sahiwal breed for milk and beef production under relatively humid conditions without nutritive stress is probably somewhere between one-fourth and one-half, with the remainder contributed by *Bos taurus* breeds that possess relatively high milk production and growth capability.

7.3 RAINFALL EFFECTS

It appears that the major effects of rainfall on herbage growth can best be ascribed to the total rainfall measured over the relevant period, commencing 1 month before the herbage quality affects the animals' performance. Table 19 illustrates the relationship between lactation yield and rainfall from 1 month before parturition until 1 month before the completion of lactation.

Table 19. Relationship between lactation yield and rainfall from 1 month before parturition until 1 month before the end of lactation

Site[a]	Milk		Rainfall		Correlation (r) and regression (b) of lactation yield (kg)/rainfall (mm)	
	$\bar{x}$ (kg)	CV (%)	$\bar{x}$ (mm)	CV (%)	r	b
Ilkerin Project	315	38	303	26	0.81	1.2
Cedarvale Farms	1666	16	412	28	0.63	1.4
Deloraine Estates	1057	8	753	11	0.47	0.5
Kilifi Plantations	2753	3	892	10	0.15	0.2
Overall					0.54	0.91

[a] Excluding El Karama Ranch, where no milk is produced.

There was an overall correlation of 0.54 between lactation yield and rainfall during the relevant period, with the correlation tending to be higher in the areas of lower rainfall. Overall, 0.91 kg of additional milk was produced per 1.0 mm of additional rainfall, ranging at the different sites from a high of 1.4 kg to a low of 0.2 kg per 1.0 mm.

Table 20 illustrates the relationship between weaning weight and rainfall

Table 20. Relationship between weaning weight and rainfall from birth to weaning

Site[a]	Weaning weight		Rainfall		Correlation (r) and regression (b) of weaning weight (kg)/rainfall (mm)	
	$\bar{x}$ (kg)	CV (%)	$\bar{x}$ (mm)	CV (%)	r	b
El Karama Ranch	170.4	5	464	13	0.92	0.12
Cedarvale Farms	163.3	9	509	16	0.83	0.14
Deloraine Estates	170.8	9	753	11	0.86	0.15
Overall					0.92	0.15

[a] Excluding Kilifi Plantations, where calves were raised artificially and early weaned, and Ilkerin Project which did not have sufficient month-of-birth data.

during the period from birth to weaning. All three situations were similar, with an overall correlation of 0.92 between weaning weight and rainfall during the relevant period. The corresponding regression was 0.15 kg additional weight at weaning per 1 mm of additional rainfall.

Table 21. Relationship between calving interval and rainfall from 3 months before previous calving date to 1 month before conception

Site[a]	Calving Interval		Rainfall		Correlation (r) and regression (b) of calving interval (days)/rainfall (mm)	
	$\bar{x}$ (days)	CV (%)	$\bar{x}$ (mm)	CV (%)	r	b
El Karama Ranch	402	2	346	17	- 0.49	- 0.08
Cedarvale Farms	424	4	370	29	0.04	- 0.01
Deloraine Estates	419	3	537	34	- 0.15	- 0.01
Kilifi Plantations	394	2	522	42	- 0.24	- 0.01
Overall					- 0.16	- 0.01

[a] Excluding Ilkerin Project which did not have sufficient month-of-parturition data.

Table 21 illustrates the relationship between calving interval and rainfall from 3 months prior to the previous calving to 1 month before conception. The overall correlation of -0.16 between calving interval and rainfall during the relevant period was not significant; the corresponding regression was -0.01.

Table 22 illustrates the relationship between calf survival to weaning and rainfall over the period from birth to weaning. The overall correlation of 0.08 between calf survival to weaning and rainfall during the relevant period was not significant.

Table 22. Relationship between calf survival to weaning and rainfall from birth to weaning

Site[a]	Viability		Rainfall		Correlation (r) and regression (b) of calf survival (%)/rainfall (mm)	
	$\bar{x}$ (%)	CV (%)	$\bar{x}$ (mm)	CV (%)	r	b
El Karama Ranch	95.1	2	464	13	- 0.03	- 0.001
Cedarvale Farms	79.4	7	509	16	0.13	0.003
Deloraine Estates	89.5	5	753	11	0.07	0.009
Overall					0.08	0.005

[a] Excluding Kilifi Plantations where calves were early weaned and raised artificially, and Ilkerin Project which did not have sufficient month-of-birth data.

Thus, rainfall over the relevant period at the five locations had a positive effect on lactation yield and weaning weight, but no significant effect on calving interval or calf survival. Differences between the sites were only significant in the case of lactation yield: for this character, the effects of rainfall were most important in the drier locations.

7.4 SEASONAL VARIATION

Seasonal variation throughout the year, as represented by the range of values for six 2-month calving periods, was reflected in many situations in all important characters. Table 23 indicates that seasonal variation was greatest in milk production, growth, viability and reproduction in that order: for all the sites combined, the differences between best and poorest 2-month calving periods were 35% for milk production, 18% for growth characters, 15% for viability and 10% for reproduction. Overall, productivity showed a difference of 16% between the best and poorest 2-month periods. Seasonal variation was greatest at Cedarvale, Ilkerin, Deloraine, Kilifi and El Karama in that order: the differences between the best and poorest seasons in terms of overall productivity were 34% at Cedarvale, 20% at Ilkerin, 11% at Deloraine, 7% at Kilifi and 5% at El Karama.

In terms specifically of milk production, seasonal variation was 59% at Ilkerin, 45% at Cedarvale, 24% at Deloraine and 11% at Kilifi. Seasonal differences in growth as reflected by weaning weight were less marked, ranging from 24% at Deloraine to 19% at Cedarvale and 11% at Ilkerin. Viability as reflected by calf survival to weaning varied according to 2-month periods by 22% at Cedarvale, 14% at Deloraine and 4% at El Karama, while reproductive performance, as reflected by calving interval, varied according to seasonal factors by 18% at El Karama, 12% at Cedarvale, 9% at Deloraine, 6% at Ilkerin and 5% at Kilifi.

The information summarized in Table 23 indicates major seasonal variations in performance, both in terms of overall productivity and the individual components of the productivity index, at Cedarvale and Ilkerin. This variation is likely due to dependence on natural grazing in areas of relatively low rainfall and variable distribution over the year. Production at Cedarvale is affected more strongly by seasonal rainfall variability than at Ilkerin, due to the much higher level of offtake at the first site and the relatively high stocking rates. Production at Deloraine is less affected by seasonal variability than at Cedarvale and Ilkerin because stocking rates are lower and rainfall is much higher and less variable.

Table 23. Difference in performance characters between best and poorest seasons

	Ilkerin	El Karama	Cedarvale	Deloraine	Kilifi	Mean
Productivity index						
difference between best and poorest (%)	20	5	34	11	7	16
CV (%)	6.9	1.7	10.7	4.4	2.4	5.2
Growth - weaning weight						
difference between best and poorest (%)	NA	11	19	24	NA	18
CV (%)	NA	4.7	8.5	9.1	NA	7.4
Milk - lactation yield						
difference between best and poorest (%)	59	-	45	24	11	35
CV (%)	38	-	15.6	7.6	3.4	16.2
Viability - calf survival						
difference between best and poorest (%)	NA	4	22	14	NA	15
CV (%)	NA	1.5	7.3	5.0	NA	4.6
Reproductive performance-calving interval						
difference between best and poorest (%)	18	6	12	9	5	10
CV (%)	7.5	2.2	4.0	3.3	2.1	3.8

Kilifi Plantations is even less affected by seasonal rainfall variability: the high offtake rate at this site is more than compensated for by the high rainfall, improved pastures and relatively high levels of supplementary feeding. El Karama is least affected by seasonal rainfall distribution: though annual rainfall is not particularly high, offtake is low and rainfall distribution throughout the year is less variable than at any other site.

7.5 YEAR EFFECTS

Table 24 illustrates the variation between the best and poorest years for overall productivity and for the four main components of the productivity index. For the five sites, records were available over an average of 4.4 years. Overall, the index of cow productivity varied by 35% from the best to the poorest year. This effect was greatest for the lower-potential sites. Differences in productivity in different years were greatest in terms of lactation yield, followed by weaning weight, calving interval and then calf survival.

Table 24. Differences in performance between best and poorest years

	Ilkerin	El Karama	Cedarvale	Deloraine	Kilifi	Mean
Productivity index						
number of years	3	6	3	4	6	4.4
difference between best and poorest(%)	60	48	26	24	18	35
CV (%)	24	15.6	11.5	8.9	7.3	13.5
Growth - weaning weight						
number of years	3	6	3	4	NA	4.0
difference between best and poorest (%)	23	27	9	26	NA	24
CV (%)	12.0	9.0	4.2	14.3	NA	9.9
Milk - lactation yield						
number of years	3	NA	3	4	6	4.0
difference between best and poorest (%)	28	NA	43	85	24	45
CV (%)	12.7	NA	17.8	24.9	8.8	16.1
Viability - calf survival						
number of years	NA	6	3	4	6	4.8
difference between best and poorest (%)	NA	9	5	11	9	9
CV (%)	NA	3.5	2.3	4.8	2.9	3.4
Reproductive performance - calving interval						
number of years	3	6	7	4	6	5.2
difference between best and poorest (%)	69	16	11	13	3	22
CV (%)	26.2	9.1	7.2	5.9	1.1	9.9

7.6 PARTURITION EFFECTS

Table 25 illustrates the difference between first and best parturition for overall productivity and the four main components of the productivity index. Overall for the four sites included in this analysis, peak productivity was reached after the fourth parturition, averaging 28% more than productivity after the first parturition. This increase was similar at all four sites, irrespective of production potential. The major effects of parturition number were on milk yield, with weaning weight, calving interval and calf survival much less affected.

Table 25. Differences in performance between first and best parturition

	El Karama	Cedarvale	Deloraine	Kilifi	Mean
Productivity index					
difference between first and best parturition (%)	29	34	28	22	28
best parturition number	6	4-5	3	5	4-5
Growth - weaning weight					
difference between first and best parturition (%)	4	11	4	NA	6
best parturition number	3	6+	4	NA	4
Milk - lactation yield					
difference between first and best parturition (%)	NA	51	28	22	34
best parturition number	NA	4-5	3	4	4
Viability - calf survival					
difference between first and best parturition (%)	8	15	7	NA	10
best parturition number	6	6+	2	NA	5
Reproductive performance - calving interval					
difference between first and best parturition (%)	17	5	11	7	10
best parturition number	6	4-5	3	9	5-6

8. THE FORMATION OF COMPOSITE BREEDS USING SAHIWAL CATTLE

8.1 THE OBJECTIVES OF CROSSBREEDING

The basic objectives of cattle crossbreeding systems are to take advantage of breed differences in additive genetic merit for specific characters so that performance characteristics are synchronized with adaptability to a given environment and with market requirements, while at the same time making the best use possible of non-additive heterosis effects. In addition, crossbreeding systems may achieve complementarity in part of a self-contained herd through the use of terminal sire breeds that have greater additive genetic merit for growth than the breed of the cow herd.

Major differences among breeds of *Bos taurus* and *Bos indicus* cattle have been demonstrated for most of the characters that contribute to production efficiency (Gregory et al, 1978a, 1978b, 1978c, 1978d, 1978e, 1979a, 1979b; Koch and Dikeman, 1977; Koch et al, 1976; Laster et al, 1976, 1979; Notter et al, 1978a, 1978b; Smith et al, 1976a, 1976b; Young et al, 1978a, 1978b). These breed differences indicate that there are probably major differences in average gene frequencies relating to economically important characters.

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Breeds of *Bos indicus* cattle differ in response capability for both milk and meat production and also in their adaptability to climate and associated factors, including tolerance of different diseases and parasites. Breeds of *Bos taurus* cattle differ substantially in performance characters associated with milk and meat production and probably in terms of adaptability to a variety of environmental conditions. Certain populations of *Bos taurus* cattle in Africa and South America have become adapted to adverse conditions through natural selection, but, similar to *Bos indicus* breeds, they have a relatively low response capability for milk and meat production when environmental conditions are improved. However, some of these populations may potentially make important contributions to composite breeds for greater milk and meat production under adverse environments.

Results based on both experimentation and computer simulation indicate that differences in additive genetic merit of breeds for specific characters can be used in crossbreeding systems to synchronize genetic resources with other production resources and to provide complementarity through the use of terminal sire breeds (Cartwright et al, 1975; Fitzhugh et al, 1975; Morris and Wilton, 1976; Notter et al, 1979; Smith, 1976; Wilton and Morris, 1976). Experimental results evaluating rotational crossbreeding systems indicate that high levels of heterosis are sustained in successive generations and that the relationship between loss of heterosis and loss of heterozygosity approaches linearity (Boston et al, 1976a, 1976b; Cartwright et al, 1964; Chapman et al, 1970, 1971; Crockett et al, 1978a, 1978b; Franke, 1978, 1979a, 1979b; Gregory and Cundiff, 1980; Koger et al, 1975; Peacock and Koger, 1979; Touchberry, 1970). These results suggest that heterosis in cattle may be primarily the result of the dominance effects of genes.

It has been shown that the cumulative effects of heterosis on characters contributing to weight of calf weaned per cow exposed to breeding are about 23% for crosses among *Bos taurus* breeds (Gregory et al, 1965; Wiltbank et al, 1967; Cundiff et al, 1974a, 1974b) and 50% or more for crosses between *Bos taurus* and *Bos indicus* breeds (Cartwright et al, 1964; Koger et al, 1975). Further, these results show that 50% or more of the observed cumulative heterosis is the result of heterosis effects on maternal traits. Thus, crossbreeding systems that are

organized to include a high percentage of the reproducing female population as crossbreds are generally favoured.

The basic outlines for two- and three-breed rotational crossbreeding systems are shown in Tables 26 and 27. The estimate of 8.5% heterosis for individual traits is based on results presented by Gregory et al (1965) and Wiltbank et al (1967) from the first phase of a comprehensive crossbreeding experiment involving the Hereford, Angus and Shorthorn breeds. Their estimate was the result of increases in survival and preweaning growth rate of crossbred calves compared with their straightbred half sibs when all calves were produced by similar straightbred dams. In the second phase of this experiment, crossbred and straightbred cows produced crossbred calves that were equal in individual heterozygosity and additive genetic composition. In this case, the crossbred cows produced 14.8% more calf weight per cow exposed to breeding as a result of both increased reproductive performance and improved maternal ability (Cundiff et al, 1974a, 1974b).

As shown by Dickerson (1969, 1973), heterozygosity stabilizes after seven generations for two- and three-breed rotation crossbreeding systems (Tables 26 and 27). The heterozygosity at equilibrium as a percentage of the maximum (F_1) for n breeds in a rotation is equal to $(2^n - 2)/(2^n - 1)$. After seven generations in a two-breed rotation system, the fluctuation in additive genetic composition reaches equilibrium with two-thirds of the breed of the sire and one-third of the breed of the maternal grandsire (Table 26). After seven generations in a three-breed rotation system, the additive genetic composition reaches equilibrium at four-sevenths of the sire breed, two-sevenths of the breed of the maternal grandsire and one-seventh of the breed of the maternal great-grandsire, which is the breed to which the females are mated (Table 27). Because of the wide fluctuation between generations in additive genetic composition in breed rotation crossbreeding systems, the breeds used in a breed rotation system should be reasonably comparable in characters such as birth weight to avoid major calving problems (Laster et al, 1973) and should be compatible in performance characteristics such as size and lactation potential to facilitate common management of all breed-of-sire groups (Cundiff, 1977).

Table 26. Genetic composition and heterosis expected in a two-breed rotation (%)

Generation	Sire breed	Additive genetic composition: Dam A	Dam B	Calf A	Calf B	Heterozygosity % relative to F_1: Dam	Calf	Estimated % increase in weight weaned per cow exposed[a]
1	A		100	50	50	0	100	8.5
2	B	50	50	25	75	100	50	19.0
3	A	25	75	63	37	50	75	13.8
4	B	63	37	31	69	75	63	16.4
5	A	31	69	66	34	63	69	15.2
6	B	66	34	33	67	69	66	15.8
7	A	33	67	67	33	66	67	15.5
8	B	67	33	33	67	67	67	15.5

[a] Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits when loss of heterosis is proportional to loss of heterozygosity.

Table 27. Genetic composition and heterosis expected in a three-breed rotation (%)

Generation	Sire breed	Additive genetic composition: Dam A	Dam B	Dam C	Calf A	Calf B	Calf C	Heterozygosity % relative to F_1: Dam	Calf	Estimated % increase in weight weaned per cow exposed[a]
1	A			100	50	0	50	0	100	8.5
2	B	50	0	50	25	50	25	100	100	23.3
3	C	25	50	25	12	25	62	100	75	21.2
4	A	12	25	62	56	12	31	75	88	18.6
5	B	56	12	31	28	56	16	88	88	20.5
6	C	28	56	16	14	28	58	88	84	20.2
7	A	14	28	58	57	14	29	84	86	19.7
8	B	57	14	29	29	57	14	86	86	20.0

[a] Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits when loss of heterosis is proportional to loss of heterozygosity.

The experiment from which Gregory et al (1965) and Wiltbank et al (1967) estimated heterosis for individual traits and Cundiff et al (1974a, 1974b) estimated heterosis for maternal traits was continued into a third phase. A preliminary analysis of the results from this experiment carried through two generations of both two- and three-breed rotational crossbreeding showed retention of heterosis equal to, and in some cases greater than, expectations relative to percentage of F_1 heterozygosity retained (Gregory and Cundiff, 1980).

Existing breeds of each species are mildly inbred lines, and to the extent that heterosis is due to the dominance effects of genes, it represents the recovery of accumulated inbreeding depression (Dickerson, 1973; Cundiff, 1977). Deviation of heterosis from linear association with heterozygosity results from the epistatic effects of genes. For loss of favourable epistatic combinations that may either have become fixed or are maintained by selection in parental breeds, loss of heterosis is greater than loss of heterozygosity; however, for loss of unfavourable epistatic combinations that may have become fixed through chance, loss of heterosis is less than loss of heterozygosity. Both genetic situations may exist, but favourable epistatic combinations are more likely to exist in parental breeds than unfavourable. Also, heterosis may be greater than heterozygosity if a threshold effect for heterozygosity should exist.

Appropriate investigations have not been conducted to show the importance of favourable epistatic combinations in cattle. There is little likelihood that fixed favourable epistatic combinations are important, however, other than for characters such as fitness for which there has been natural or automatic selection, because the selection goals that have generally characterized cattle breeding are continuously changing.

The higher level of heterosis achieved between crosses of *Bos indicus* and *Bos taurus* breeds than between crosses of *Bos taurus* breeds alone is well documented for beef production characters (Cartwright et al, 1964; Koger et al, 1975; Peacock and Koger, 1979; Crockett et al, 1978a, 1978b). Much of this

higher level of heterosis may be the result of a low level of climatic adaptability, and thus of poor purebred performance, of the *Bos taurus* breeds included in these studies and perhaps a low production response capability of the *Bos indicus* breeds studied in a moderately intensive beef production environment. The crossbred is a genetic intermediate that is most likely better suited than the parental pure breeds for both adapting to the climatic environment and meeting beef production requirements in moderately intensive production systems (Cundiff, 1970). Major differences in level of heterosis probably do not exist between crosses of *Bos taurus* breeds which are reasonably well adapted to a given production environment (Gregory et al, 1978a, 1978b, 1978d, 1978e). Breeds that show generally higher mean heterosis in crosses with other breeds are probably relatively highly inbred: the higher average heterosis may be the result of greater accumulated inbreeding depression reflected in their contribution to the purebred mean.

8.2 THE FORMATION OF COMPOSITE BREEDS AS AN ALTERNATIVE TO ROTATIONAL CROSSBREEDING SYSTEMS

The utilization of heterosis through organized breed rotation crossbreeding systems is restricted in many situations due to two factors. For one thing, the fluctuation between generations in additive genetic composition may severely limit the achievement of optimum contributions by different breeds. For instance, in a two-breed rotation crossbreeding system, the genes contributed by the breeds of the sire and the maternal grandsire fluctuate between one-third and two-thirds between generations.

Such wide fluctuations between generations make it difficult to synchronize climatic adaptability and performance characteristics appropriate to a given management level and natural environment. If *Bos indicus* breeds should contribute one-fourth or one-half of total germ-plasm to achieve the best climatic adaptability, then rotational crossbreeding systems using pure *Bos indicus* and *Bos taurus* sires will not provide the optimum *Bos indicus* input consistently (Tables 26 and 27). Also, because of the requirement to use compatible breeds in a rotation,

rotational crossbreeding systems cannot exploit complementarity (Cartwright, 1970) unless they are combined with terminal-sire systems by breeding mature cows to terminal sires after replacements are produced in a breed-rotation system with younger cows (Notter et al, 1979).

The second major limitation on the use of breed rotation crossbreeding systems is the fact that a substantial proportion of the world's cattle population is kept in management units which are too small to use crossbreeding systems on a self-contained basis. An alternative or supplement to crossbreeding systems is needed to utilize heterosis and to achieve the most favourable additive genetic composition so that a high production response capability for milk and beef production in specific climatic, nutritional, disease and parasite environments is obtained. The formation of composite breeds based on a multibreed foundation is a potentially attractive alternative or supplement to continued crossbreeding. Once a composite breed is formed on the basis of initial crossbreeding, the animals are allowed to breed freely *inter se*. Thus, the herd is managed as a straightbred population and the management problems that are associated with small herd size in a rotational crossbreeding system are avoided.

A further potential advantage of composite breeds is that their response to selection should be greater than that of parental breeds because of increased genetic variation. Greater selection intensity is also possible as a result of a higher reproduction rate due to heterosis (Dickerson, 1973; Cundiff, 1977).

Wright (1922) showed that retention of initial heterozygosity following crossing and subsequent random mating within the crosses is proportional to (n-1)/n where n is the number of breeds included in the cross, assuming equal contribution by each breed. The loss in heterozygosity occurs between the F_1 and F_2 generations. Table 28 provides information on the level of heterozygosity relative to the F_1 which is retained after equilibrium is reached for two-, three- and four-breed rotation crossbreeding systems and is presented for comparative purposes for two-, three-, four-, five-, six-, seven and eight-breed composites, with breeds con-

Table 28. Heterozygosity of different mating types and estimated increase in performance as a result of heterosis

Mating type	Heterozygosity % relative to F_1	Estimated % increase in weight weaned per cow exposed[a]
Pure breeds	0	0
Two-breed rotation	66.7	15.5
Three-breed rotation	85.7	20.0
Four-breed rotation	93.3	21.7
Two-breed composite:		
F_3: 1/2A, 1/2B	50.0	11.6
F_3 5/8A, 3/8B	46.9	10.9
F_3: 3/4A, 1/4B	37.5	8.7
Three-breed composite:		
F_3: 1/2A, 1/4B, 1/4C	62.5	14.6
F_3: 3/8A, 3/8B, 1/4C	65.6	15.3
Four-breed composite:		
F_3: 1/4A, 1/4B, 1/4C, 1/4D	75.0	17.5
F_3: 3/8A, 3/8B, 1/8C, 1/8D	68.8	16.0
F_3: 1/2A, 1/4B, 1/8C, 1/8D	65.6	15.3
Five-breed composite:		
F_3: 1/4A, 1/4B, 1/4C, 1/8D, 1/8E	78.1	18.2
F_3: 1/2A, 1/8B, 1/8C, 1/8D, 1/8E	68.8	16.0
Six-breed composite:		
F_3: 1/4A, 1/4B, 1/8C, 1/8D, 1/8E, 1/8F	81.3	18.9
Seven-breed composite:		
F_3: 3/16A, 3/16B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G	85.2	19.8
Eight-breed composite:		
F_3: 1/8A, 1/8B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G, 1/8H	87.5	20.4

[a] Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits, assuming that loss of heterosis is proportional to loss of heterozygosity. This assumption has not been validated for composite breeds.

tributing in different proportions in several instances. Heterozygosity relative to the F_1 generation has been adjusted in the composite populations in which contribution by parental breeds is unequal. Percentage of mean F_1 heterozygosity retained is proportional to $1 - \sum_i^n P_i^2$, where P_i is the fraction of each of n breeds used in the pedigree of a composite breed; i.e. the heterozygosity retained in a three-breed composite formed from 3/8 breed A, 3/8 breed B and 1/4 breed C is equal to $1 - [(3/8)^2 + (3/8)^2 + (1/4)^2]$ or 65.6. Obviously, as many breeds as possible should be used which can contribute to a favourable additive genetic composition for the production and marketing situation because retention of heterozygosity is a function of the number of breeds included in the foundation (Wright, 1922; Dickerson, 1969, 1973). Based on the assumption that loss of heterosis is approximately proportional to loss of heterozygosity, estimates of increase in weight produced per cow exposed to breeding for beef production systems are presented in Table 28 for each mating type. The assumption that loss of heterosis is proportional to loss of heterozygosity has not been validated for composite breeds of beef cattle, however, or for any other species. The heterosis levels on which the estimates in Table 28 are based are appropriate for crosses of *Bos taurus* breeds. As mentioned earlier, heterosis has been shown to be greater in crosses of *Bos taurus* with *Bos indicus* breeds.

Dickerson (1969) was the first to point out that composite breeds may have performance advantages from retained heterosis approaching those obtainable by more complex crossbreeding systems. He discusses the possible importance of loss in composite breeds of favourable epistatic combinations that may either have become fixed or are maintained by selection in the parental breeds and presents documentation of recombination loss of epistatic superiority of parental populations in *Drosophila*, in maize and in poultry. Livestock breeding experiments have not been designed to determine the importance of recombination loss of epistatic purebred superiority, however, because of the problem of separating heterosis retention in composite breeds from the renewed inbreeding and selection which are generally practised immediately after formation of composite populations. Dickerson (1969) emphasizes the importance of maintaining sufficiently large populations so that the

initial advantage of increased heterozygosity is not dissipated by early re-inbreeding of composite breeds. Perhaps the failure of some early efforts at composite cattle breed formation was due to early re-inbreeding and the use of a small number of inadequately characterized parental breeds.

Although composite breed formation would not provide directly and immediately the advantage of mating sires with high breeding value for growth rate to dams of smaller mature size, it does make it possible, through between-breed selection, to increase general adaptability to the climatic and/or nutritive environment at a rapid rate. Further, if specific crossbreeding systems are indicated through the use of breeds that excel in either paternal or maternal characters, composite breed formation provides the opportunity to optimize additive genetic composition rapidly for specific role(s) through the choice of foundation breeds that may be specialized for either paternal or maternal use.

To make composite breed formation a predictable procedure, however, candidate foundation breeds need to be characterized in a range of environments and the extent to which the loss of heterosis is linearly associated with loss of heterozygosity needs to be determined. Information is already available characterizing a number of *Bos taurus* and *Bos indicus* breeds in different ecological zones. Although much of this information may be observational or subjective in nature, it is probably adequate to identify with reasonable precision candidate foundation breeds for the establishment of promising composite breeds in different environments. The simultaneous characterization of environments is also necessary to extend the relevance of breed characterization data to the broadest possible range of production situations.

At the same time, experiments are in progress at the U S Meat Animal Research Center in Clay Center, Nebraska, to determine the linearity of association of loss of heterosis and loss of heterozygosity in composite cattle populations and to determine selection response in composite populations compared to the pure foundation breeds. Even if the loss of heterosis in composite breeds should prove to be

greater than the loss of heterozygosity, however, the formation of composite breeds may still be the most promising approach to increasing genetic response for meat and milk production in a variety of environments.

The inclusion of the maximum number of breeds of demonstrated potential in the composite will result in the retention of the highest proportion of original (F_1) heterosis. The population of a new composite breed should also be sufficiently large so that the initial advantage of increased heterozygosity is not dissipated by early re-inbreeding. It is suggested that not less than 12 sires be used per generation: this number will result in a rate of increased inbreeding of only about 1% per generation. Once the composite breed is formed in a given production environment, further selection within the population should focus on criteria that contribute to increased meat and milk production, as these factors will also reflect adaptability.

8.3 THE USE OF COMPOSITE BREEDS WITH A SAHIWAL COMPONENT IN TROPICAL AFRICA

Trail (1980) classified Africa south of the Sahara from the standpoint of cattle adaptability considerations into five ecological zones based primarily on the criteria of rainfall and elevation. The five ecological zones are listed in Table 29, along with their estimated cattle populations and the percentage of the total regional cattle population ascribed to each zone (FAO, 1977).

It is recognized that variations in rainfall distribution, elevation, soil fertility, solar radiation, temperature and relative humidity within each of these five ecological zones influence the climate and the nutritional, disease and parasite environment and thus the type of cattle that are adapted and their response capability for milk and beef production. Trail (1980) expressed the view that the environment of the arid to semi-arid ecological zone generally favours indigenous and improved indigenous cattle, while the environment of the semi-arid to humid ecological zone can support exotic-indigenous crosses. He further concluded that parts of the

Table 29. Cattle populations in sub-Saharan Africa by ecological zone

Ecological zone	Annual rainfall	Estimated cattle population	Percentage of total for sub-Saharan Africa
Very arid	<400 mm	9 000 000	6%
Arid to semi-arid	400-600 mm	33 000 000	22%
Semi-arid to humid	>600 mm	66 000 000	44%
Temperate highlands	>600 mm	33 000 000	22%
Humid, tsetse-infested	>600 mm	9 000 000	6%
Total		150 000 000	100

Source: FAO (1977).

temperate highlands can support pure exotic *Bos taurus* cattle from the standpoint of climatic considerations as long as the nutritive environment is sufficient to support their high milk and meat production response capability.

It is appropriate here to consider the development of composite breeds involving a contribution by the Sahiwal for meat and milk production in the semi-arid to subhumid ecological zones where 44% of the cattle in Africa south of the Sahara are located. Consideration is also given to the use of Sahiwals in the lower-potential areas of the temperate highlands and the higher-potential areas of the semi-arid highlands. The herds that contributed records to this study are located as shown in Table 30.

From the standpoint of level of nutritive environment, the five herds are ranked from highest to lowest, in the order listed in Table 30, with perhaps minimal difference between Deloraine Estates and Cedarvale Farms. For rank on nutritive environment from the standpoint of output, El Karama Ranch would perhaps be ranked equal to Kilifi Plantations because most of the output at El Karama is beef. Even though both Deloraine and Cedarvale are classified in the temperate highlands,

Table 30. Ecological zones of study sites in Kenya

Herd	Ecological zone
Kilifi Plantations	subhumid
Deloraine Estates	temperate highlands (lower- to middle-potential area of zone)
Cedarvale Farms	temperate highlands (lower-potential area of zone)
El Karama Ranch	semi-arid highlands (higher-potential area of zone)
Ilkerin Project	semi-arid highlands (higher-potential area of zone)

the nutritive environment provided, as determined by economic feasibility, is not considered adequate to support pure *Bos taurus* cattle successfully, though Deloraine maintains some straightbred Ayrshire cows on a preferential treatment basis.

The Sahiwal breed has the greatest potential for milk production among the *Bos indicus* breeds generally available in Africa. It is also assumed that the Sahiwal breed is approximately equal to indigenous breeds of *Bos indicus* cattle in terms of adaptability in the ecological zones of Africa that are the focus of this study. Results from the analysis of records from the five herds in Kenya provide the basis for this assumption. Based on the records of herds composed of Sahiwals in various combinations with other *Bos indicus* and *Bos taurus* breeds, an appropriate strategy for maximizing milk and beef production in a given environment appears to be the formation of a specific composite breed for each location, including different proportions of the Sahiwal breed. In the ecological zones where the five herds are located, a minimum Sahiwal contribution of one-fourth is needed to provide adaptability to the climatic, nutritive, disease and parasite environment, while a Sahiwal contribution of more than three-fourths would probably not be favourable in terms of maximizing milk and beef production.

Table 31 gives the breed composition and the percentage of heterozygosity retained relative to the F_1 generation for the reciprocal crosses of 11 different breeds and breeding groups represented in the five herds under analysis. The values given in this table for the percentage of heterozygosity retained emphasize the desirability of including three breeds, rather than two, in the foundation of a composite breed, and the importance of having approximately equal contributions by each breed if this can be done while at the same time achieving optimum additive genetic composition. In a composite breed based on equal contributions by three breeds, the proportion of mean F_1 heterozygosity would be

$$1 - \left[(1/3)^2 + (1/3)^2 + (1/3)^2\right] = 2/3, \text{ or } 0.67.$$

A composite breed based on equal contributions by four breeds would retain an even higher proportion of mean F_1 heterozygosity, or

$$1 - \left[(1/4)^2 + (1/4)^2 + (1/4)^2 + (1/4)^2\right] = 3/4, \text{ or } 0.75.$$

The percentage of mean F_1 heterozygosity retained by these two composite breeds should be compared with the level of 0.67 retained by a two-breed rotation crossbreeding system and 0.86 retained by a rotation crossbreeding system with three breeds.

The selection of foundation breeds for inclusion in a composite breed needs to be based on performance under environmental conditions similar to those in which the composite breed will be maintained. For instance, a comprehensive experiment involving Hereford cattle (Pahnish et al, 1979; Butts et al, 1971) showed the importance of the interaction of genotype with climate and associated forage resources. In an environmental situation which favours a contribution by *Bos indicus* breeds greater than one-fourth, a three-breed composite including the Boran breed, as well as the Sahiwal and a *Bos taurus* breed, would be desirable. The milk and beef production potential of the Boran breed is approximately equal to that of the Sahiwal over a range of African environments.

The *Bos taurus* stock used in the crossbreeding programmes described in this study were originally imported from Europe or North America. There they

Table 31. Breed composition and heterozygosity of progeny from different mating types

Breed Dam Group[a]	Sire Breed Group[a] 1 Sahiwal	2 Ayrshire	3 Friesian	4 Brown Swiss	5 3/4S - 1/4A
1. Sahiwal	-	1/2S - 1/2A	1/2S - 1/2F	1/2S - 1/2B	-
heterozygosity % relative to F_1		50.0	50.0	50.0	
2. Ayrshire	1/2S - 1/2A	-	-	-	3/8S - 5/8A
heterozygosity % relative to F_1	50.0				46.9
3. Friesian	1/2S - 1/2F	-	-	-	3/8S - 1/8A - 1/2F
heterozygosity % relative to F_1	50.0				59.4
4. Brown Swiss	1/2S - 1/2B	-	-	-	3/8S - 1/8A - 1/2B
heterozygosity % relative to F_1	50.0				59.4
5. 3/4S - 1/4A	-	3/8S - 5/8A	3/8S - 1/8A - 1/2F	3/8S - 1/8A - 1/2B	3/4S - 1/4A
heterozygosity % relative to F_1		46.9	59.4	59.4	37.5
6. 1/2S - 1/2A	3/4S - 1/4A	1/4S - 3/4A	1/4S - 1/4A - 1/2F	1/4S - 1/4A - 1/2B	5/8S - 3/8A
heterozygosity % relative to F_1	37.5	37.5	62.5	62.5	49.9
7. 1/4S - 3/4A	5/8S - 3/8A	-	-	-	1/2S - 1/2A
heterozygosity % relative to F_1	46.9				50.0
8. 2/3S - 1/3A	-	1/3S - 2/3A	1/3S - 1/6A - 1/2F	1/3S - 1/6A - 1/2B	17/34S - 7/34A
heterozygosity % relative to F_1		44.5	61.1	61.1	41.3
9. 1/3S - 2/3A	2/3S - 1/3A	-	-	-	13/34S - 11/34A
heterozygosity % relative to F_1	44.5				49.6
10. 1/2S - 1/2F	3/4S - 1/4F	1/4S - 1/4F - 1/2A	1/4S - 3/4F	1/4S - 1/4F - 1/2B	5/8S - 1/8A - 1/4F
heterozygosity % relative to F_1	37.5	62.5	37.5	62.5	53.1
11. 1/2S - 1/2B	3/4S - 1/4B	1/4S - 1/4B - 1/2A	1/4S - 1/4B - 1/2F	1/4S - 3/4B	5/8S - 1/8A - 1/4B
heterozygosity % relative to F_1	37.5	62.5	62.5	37.5	53.1

a S = Sahiwal, A = Ayrshire, F = Friesian and B = Brown Swiss.

Table 31, cont.

Breed Dam Group[a]		Sire Breed Group[a]					
		6 1/2S - 1/2A	7 1/4S - 3/4A	8 2/3S - 1/3A	9 1/3S - 2/3A	10 1/2S - 1/2F	11 1/2S - 1/2B
1.	Sahiwal	3/4S - 1/4A	5/8S - 3/8A	-	2/3S - 1/3A	3/4S - 1/4F	3/4S - 1/4B
	heterozygosity % relative to F_1	37.5	46.9		44.5	37.5	37.5
2.	Ayrshire	1/4S - 3/4A	-	1/3S - 2/3A	-	1/4S - 1/2A - 1/4F	1/4S - 1/2A - 1/4B
	heterozygosity % relative to F_1	37.5		44.5		62.5	62.5
3.	Friesian	1/4S - 1/4A - 1/2F	-	1/3S - 1/6A - 1/2F	-	1/4S - 3/4F	1/4S - 1/2F - 1/4B
	heterozygosity % relative to F_1	62.5		61.1		37.5	62.5
4.	Brown Swiss	1/4S - 1/4A - 1/2B	-	1/3S - 1/6A - 1/2B	-	1/4S - 1/2B - 1/4F	1/4S - 3/4B
	heterozygosity % relative to F_1	62.5		61.1		62.5	37.5
5.	3/4S - 1/4A	5/8S - 3/8A	1/2S - 1/2A	17/24S - 7/24A	13/24S - 11/24A	5/8S - 1/8A - 1/4F	5/8S - 1/8A - 1/4B
	heterozygosity % relative to F_1	46.9	50.0	41.3	49.6	53.1	53.1
6.	1/2S - 1/2A	1/2S - 1/2A	3/8S - 5/8A	7/12S - 5/12A	5/12S - 7/12A	1/2S - 1/4A - 1/4F	1/2F - 1/4A - 1/4B
	heterozygosity % relative to F_1	50.0	46.9	48.6	48.6	62.5	62.5
7.	1/4S - 3/4A	3/8S - 5/8A	1/4S - 3/4A	11/24S - 13/24A	7/24S - 17/24A	3/8S - 3/8A - 1/4F	3/8S - 3/8A - 1/4B
	heterozygosity % relative to F_1	46.9	37.5	49.6	41.3	65.6	65.6
8.	2/3S - 1/3A	7/12S - 5/12A	11/24S - 13/24A	2/3S - 1/3A	1/2S - 1/2A	7/12S - 1/6A - 1/4F	7/12S - 1/6A - 1/4B
	heterozygosity % relative to F_1	48.6	49.6	44.5	50.0	56.9	56.9
9.	1/3S - 2/3A	5/12S - 7/12A	7/24S - 17/24A	1/2S - 1/2A	1/3S - 2/3A	5/12S - 1/3A - 1/4F	5/12S - 1/3A - 1/4B
	heterozygosity % relative to F_1	48.6	41.3	50.0	44.5	65.3	65.3
10.	1/2S - 1/2F	1/2S - 1/4A - 1/4F	3/8S - 3/8A - 1/4F	7/12S - 1/6A - 1/4F	5/12S - 1/3A - 1/4F	1/2S - 1/2F	1/2S - 1/4F - 1/4B
	heterozygosity % relative to F_1	62.5	65.6	56.9	65.3	50.0	62.5
11.	1/2S - 1/2B	1/2S - 1/4A - 1/4B	3/8S - 3/8A - 1/4B	7/12S - 1/6A - 1/4B	5/12S - 1/3A - 1/4B	1/2S - 1/4B - 1/4F	1/2S - 1/2B
	heterozygosity % relative to F_1	62.5	65.6	56.9	65.3	62.5	50.0

a S = Sahiwal, A = Ayrshire, F = Friesian and B = Brown Swiss.

were selected according to their performance levels in a temperate climate, which is probably not an appropriate indicator of performance in the tropics. Since it was first introduced, however, the Ayrshire breed has been used extensively in all the production environments covered in this study and the adaptability and response capability for milk and beef production of Ayrshire crosses have been well documented. In addition, limited information available from Cedarvale Farms indicates that Sahiwal crosses with the Friesian breed are comparable with equivalent Sahiwal x Ayrshire crosses in terms of several production characters. At Kilifi Plantations, limited use has also been made of the Brown Swiss breed in a crossbreeding programme with Sahiwals and Ayrshires, and initial results are promising. Although limited use has been made of Simmental sires at Deloraine Estates, sufficient data on their progeny were not available to assess their potential contribution to composite breeds in similar environments.

A four-breed composite based on equal contributions by the Sahiwal, Ayrshire, Friesian and Brown Swiss breeds could be created by crossing Friesian-Brown Swiss sires with Sahiwal-Ayrshire cows. Such a breed should be well adapted to the climatic environment represented by Deloraine Estates. However, the nutritive requirements for such a composite breed would likely be in the range of the level provided by Kilifi Plantations. Such a composite may be on the borderline in terms of climatic adaptability at Kilifi, with only one-fourth Sahiwal contribution, but this might be adequate given the favourable nutritive environment.

The results from the analysis of records contributed by the five herds provide a basis for suggesting specific composite breeds for each environmental situation. All possible reciprocal crosses of the 11 breeds and breeding groups represented in the five herds under study are shown in Table 31. The level of initial heterozygosity retained in the various potential composite breeds depicted in the table ranges from 0.375 to 0.656.

Detailed suggestions for composite breed formation in specific situations must be based on considerations of the natural environment, the level of manage-

ment which is economically feasible and the relative importance of milk and beef as production goals. More specifically, consideration needs to be given to average temperatures, rainfall amount and distribution, solar radiation, relative humidity, soil fertility and the quality of natural forages available, along with the degree of environmental modification which is economically justified and technically feasible. Input costs and output values need to be projected for the medium and longer term, because the development of composite breeds has both intermediate and longer-term implications. The five situations described in this study vary considerably in terms of climatic factors, potential nutritive environment and production goals.

For environmental situations represented by Ilkerin, which lies in a higher-potential area of the arid to semi-arid ecological zone, the optimum combination for a composite breed may be in the range of five-eighths to three-fourths Sahiwal with the Ayrshire breed contributing the remaining one-fourth to three-eighths. These combinations, however, have the disadvantage of retaining relatively low proportions of initial heterozygosity. A 5/8 Sahiwal - 3/8 Ayrshire combination would retain 0.469 of F_1 heterozygosity, while a 3/4 Sahiwal - 1/4 Ayrshire combination would retain only 0.375 (Table 31).

El Karama Ranch also lies in a higher-potential area of the arid to semi-arid ecological zone. In this environment the Sahiwal breed should probably contribute from three-eighths to five-eighths to a composite breed with the Ayrshire breed a strong candidate to contribute the remainder. Such a composite breed would retain a minimum of 0.469 of F_1 heterozygosity, or 0.50 if the Sahiwal and Ayrshire breeds each contribute equally.

Cedarvale Farms lies in a lower-potential area of the temperate highlands. Suitable composite breeds for this situation, as shown in Table 31, might be reciprocal cross combinations 10-2 (1/4S - 1/2A - 1/4F) or 11-2 (1/4S - 1/2A - 1/4B). An Ayrshire contribution of one-half is suggested, with no more than one-fourth of either Friesian or Brown Swiss, because Ayrshires are probably more

suited to this fairly restricted feed environment because of their smaller size and lower milk production potential. The two composite breeds suggested would retain 0.625 of the mean heterozygosity.

Deloraine Estates lies in a lower- to middle-potential area of the temperate highlands, with temperatures similar to those at Cedarvale but with higher average rainfall. For such environmental situations, with some improvement in the natural nutritive environment, a number of composite breeds appear promising. These are shown in Table 31 as reciprocal cross combinations 10-2 (1/4S - 1/2A - 1/4F), 10-4 (1/4S - 1/2B - 1/4F), 11-2 (1/4S - 1/2A - 1/4B) and 11-3 (1/4S - 1/2F - 1/4B). All of these composite breeds would retain 0.625 of the mean F_1 heterozygosity.

Kilifi Plantations lies in the subhumid zone, with a relatively favourable nutritive environment but a rather stressful climate. The nutritive environment will support a fairly high response capability, so that a number of composite breeds may be considered, as shown in Table 31. These would include reciprocal cross combinations 11-6 (1/2S - 1/4A - 1/4B), 11-7 (3/8S - 3/8A - 1/4B), 11-8 (7/12S - 1/6A - 1/4B), 11-9 (5/12S - 1/3A - 1/4B), 11-10 (1/2S - 1/4F - 1/4B), or possibly reciprocal cross combinations 10-6 (1/2S - 1/4A - 1/4F), 10-7 (3/8S - 3/8A - 1/4F), 10-8 (7/12S - 1/6A - 1/4F) or 10-9 (5/12S - 1/3A - 1/4F). A Brown Swiss contribution might be favoured over a similar Friesian contribution because a composite breed with one-half Brown Swiss and the remainder Sahiwal and Ayrshire has shown from initial trials to be adapted to this climatic and feed environment. A composite breed of reciprocal cross combinations 10-11 (1/2 Sahiwal - 1/4 Friesian - 1/4 Brown Swiss) should also be well adapted to this environment with a relatively high response capability for both milk and beef production. A contribution by the Sahiwal breed in the range of three-eighths to seven-twelfths should favour climatic adaptability. The range in percentage of mean F_1 heterozygosity retained in the composite breeds suggested is from 0.569 to 0.656, which approaches the level achieved in a two-breed rotation crossbreeding system (Table 26).

SUMMARY

Productivity data are presented and evaluated for

- purebred Sahiwal (*Bos indicus*) cattle,
- Sahiwals crossed in different combinations with cattle of the Ayrshire, Friesian and Brown Swiss (*Bos taurus*) breeds,
- purebred Ayrshire (*Bos taurus*) cattle,
- cattle of two indigenous *Bos indicus* breeds, Boran and East African Zebu

reared under different environmental conditions in Kenya, varying from sea level to 2200 m and from 610 to 1043 mm mean annual rainfall. These environments include the subhumid ecological zone, the lower- to middle-potential areas of the temperate highlands and the higher-potential areas of the semi-arid highlands of sub-Saharan Africa. The data derive from five ranches whose production objectives varied from primarily beef to primarily milk production, with different levels of emphasis in between.

A primary objective of this study was to evaluate the potential for both milk and beef production of the Sahiwal breed in various African environments. The focus was on Sahiwal cattle as contributors of *Bos indicus* germ-plasm to populations also based on *Bos taurus* breeds, as the Sahiwal breed is known to have the greatest potential for milk production among the *Bos indicus* breeds generally available in Africa. *Bos indicus* cattle generally have a low response capability for milk and beef production characters as straightbreds, but they are well adapted to the African climatic and nutritive environments represented by the five locations which contributed data for this study. These environments are not adequate in terms of climate or feed resources to support the high milk and beef

production response capability of *Bos taurus* breeds. It is also not economically or technically feasible to modify these environments sufficiently to meet the requirements of the high-performing *Bos taurus* breeds. Thus, this study included an examination of concepts and approaches for combining the adaptability characteristics of the Sahiwals with the high-performance characteristics of *Bos taurus* breeds to achieve and maintain the most favourable additive genetic composition for production in the given environments.

In two of the higher-potential locations (Deloraine Estates and Cedarvale Farms) Sahiwal crosses with *Bos taurus* breeds were markedly superior to purebred Sahiwals in terms of characters relating to milk production and an index of cow productivity. In what should be the highest-potential site (Deloraine Estates) situated in the temperate highlands at an elevation of 2100 m with 1007 mm annual rainfall, the Ayrshire-Sahiwal cross cows exceeded the straightbred Ayrshire cows by 3.8% in terms of a productivity index per cow, in spite of the preferential feeding provided to the straightbred Ayrshires. The straightbred Ayrshire cows produced 185 kg more milk per lactation than the Ayrshire-Sahiwal crosses, but the higher calving percentage and higher calf survival rate of the crosses resulted in a higher index of cow productivity.

For the three highest-potential units (Kilifi Plantations, Deloraine Estates and Cedarvale Farms) where the primary objective was milk production, both milk production and the cow productivity index were reduced when the Sahiwal breed contributed more than one-half of the germ-plasm to a population where the remainder was contributed by the Ayrshire breed. In the herd that provided the highest nutritive environment and had the highest level of milk production (Kilifi Plantations), the 2/3 Ayrshire - 1/3 Sahiwal crosses were superior in most characters related to milk production, including the cow productivity index, over the 1/3 Ayrshire - 2/3 Sahiwal crosses, even though the herd is located in a relatively stressful climatic environment at sea level, 3.5^{o} latitude south. Thus, it is

concluded that the Ayrshire breed excels the Sahiwal breed in transmitted effects for milk production. On the basis of results from a relatively wet area in the sub-humid ecological zone, a lower- to middle-potential area in the temperate highlands, and a lower-potential area in the temperate highlands, the optimum contribution by the Sahiwal breed appears to be in the range of one-fourth to one-half, with the remainder contributed by *Bos taurus* breeds.

When straightbred Sahiwals were compared with indigenous Boran cattle in a beef production environment representative of the higher-potential areas of the semi-arid highlands, the differences between the two breeds were small for most characters evaluated. In terms of fitness-related characters, the Sahiwal breed proved well adapted to the environment. The Sahiwals excelled the Boran in maternal ability, while the Boran excelled in transmitted effects for growth. When credited with milk extracted for domestic use, the Sahiwals proved superior to the Boran in terms of a cow productivity index. It is concluded that the Sahiwal breed can make a useful contribution to beef production programmes in the higher-potential areas of the arid to semi-arid ecological zone. Their greatest potential contribution in this zone is either through organized crossbreeding systems to use heterosis or as a contributor to composite breeds. Results from Deloraine Estates and Cedarvale Farms show the Sahiwal breed superior to the Ayrshire in transmitted effects for growth rate, indicating that Sahiwals can usefully be included in programmes geared towards beef production.

At the Ilkerin Project in a higher-potential area of the semi-arid highlands, the Sahiwal breed greatly excelled the indigenous Small East African Zebu in characters related to milk production and growth. Further, the Sahiwals averaged a 38-day shorter calving interval, which indicates a high level of adaptability to a fairly harsh nutritional environment.

Although available data were limited for obtaining reliable estimates of heterosis, the estimates made are in general agreement with prior reports. The importance of heterosis for both milk and beef production characters is well docu-

mented, particularly in the case of crosses of *Bos taurus* and *Bos indicus* breeds.

The optimum contribution of each foundation breed cannot be achieved and maintained by a two-breed rotation crossbreeding system because of the fluctuation between generations of one-third to two-thirds in genes contributed by the breed of the sire and of the maternal grandsire. Furthermore, substantial numbers of cattle throughout the world are kept in herds which are too small to use organized crossbreeding systems on a self-contained basis. In these situations, the formation of composite breeds is a logical alternative, based on comprehensive characterization of foundation breeds in the relevant climatic and nutritive environments.

In addition, composite breed formation has the advantage of utilizing the effects of heterosis. Retention of initial heterozygosity after crossing and subsequent random mating with the crosses *(inter se)* is proportional to $1 - \sum_{i}^{n} P_i^2$ where P_i is the fraction of each of n breeds contributing to the composite breed. Thus, retention of heterozygosity favours including as many breeds as possible in a composite breed as long as each makes a positive contribution to average additive genetic merit. A further important consideration in the formation of composite breeds is to maintain a sufficiently large population so that the initial advantage of increased heterozygosity is not dissipated by early re-inbreeding.

Loss of heterosis has been shown to be proportional to loss of heterozygosity in breed rotation crossbreeding systems. The importance of the contribution to composite breeds of favourable epistatic genetic combinations that either have become fixed or are maintained by selection in parental breeds has not been determined in cattle. To the extent that such favourable epistatic genetic combinations contribute to increased performance in parental purebreds, the loss in performance in composite breeds would be greater than the loss of heterozygosity relative to initial heterozygosity reflected by the mean for the F_1 crosses of the parental breeds. Results from rotation crossbreeding systems show loss of heterosis to be linearly associated with loss of heterozygosity in cattle, but also indicate that heterosis may

be primarily the result of the dominance effects of genes. If this is so, composite breeds may have performance advantages from retained heterosis approaching those obtainable from rotational crossbreeding. The linear association between loss of heterosis and loss of heterozygosity in composite breeds still needs to be demonstrated, along with the additive genetic variation of composite breeds relative to their parental breeds, particularly for characters related to fitness. Research is currently in progress, at the U S Meat Animal Research Center in Clay Center, Nebraska, which addresses these two relevant issues.

Suggestions are presented for specific composite breeds in each of the environmental situations for which data were analyzed. The primary objective is to synchronize the formation of a composite breed with the natural environment in which the herd is to be maintained, including climatic, nutritive, disease and parasite conditions, with the level of management which is technically and economically feasible and with specific production goals. The Sahiwal breed has been selected to contribute from one-fourth to three-fourths of the germ plasm for each of the composite breeds suggested. There are strong indications that the optimum contribution by a *Bos indicus* breed is at least one-fourth in any of the environmental situations described in this study.

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